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Application of Symbolic Processing to Command and Control

Final Technical Report

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Final Technical Report

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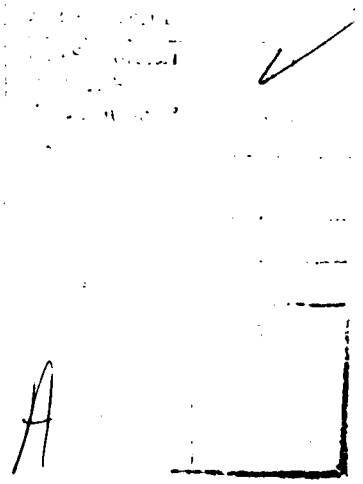

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This paper describes an effort to evolve and apply a symbolic processing paradigm for Command and Control (C2) systems. The specific application discussed is an 'intelligent' graphics interface to support time-critical C2 decision tasks. This Advanced Interactive Presentation System (AIPS) replaces the separate and specialized graphics interfaces of individual decision-support application programs, providing the user with over

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Item 20. (Continued) a highly automated agent through which to interactively direct and modify the generation of displays whose content cuts across sub-system boundaries. The key to providing this high level of automation lies in the correct representation of knowledge about graphics, the display device, the application domain, and the user's needs.

An experimental AIPS has been constructed utilizing a high-level knowledge representation language (KLONE) implemented as part of this effort. This system manipulates general descriptions of information presentation concepts such as domain objects, coordinate systems, transformations, display regions, display objects, and the relationships between domain objects and their depictions. This paper introduces the Information Presentation System concept, describes the KLONE knowledge language and details the current state of the experimental AIPS.

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1. INTRODUCTION

1.1 Premises of the Research

We believe that the problem with current command and control (C2) systems is the general view of what those systems ought to be, and not any particular equipment or algorithms utilized in them. It is the nature of C2 systems that we must comprehend more fully, and in a manner suited to providing guidance for system design. Real-time symbolic processing technology can provide a comprehensive new paradigm for C2 systems, and the necessary hardware, software, and conceptual resources have developed to the point where it is possible to meaningfully explore the implications. This paradigm and its supporting technology offer the potential for solving many of the problems that have been intractable heretofore in the military's search for operationally useful and usable command and control systems.

Currently, there are two prevalent paradigms for C2 systems. The first is that a C2 system is a communications system. That is, its purpose is to facilitate communications between the commanders who must make the decisions. Taken to its extreme, the position is that since direct voice communications between people is one of the most efficient means we have today, a C2 system that is an advanced telephone network (reliable, secure, etc.) would "solve the command and control problem". A more sophisticated interpretation is that the data and models stored in a C2 system are themselves a communications mechanism between people, and that the communications function incorporates much more than simple person-to-person voice links.

The second common paradigm of a C2 system defines it as a data repository. From this view, the completeness, relevance,

accuracy, reliability and accessibility of data are the primary issues. The crucial problem with the data paradigm is that data per se is not information; often the more massive the data, the less the information that can be derived from it. The data involved is invariably low-level and as detailed as current technology and economics will allow. But the items of greatest interest to the commander are situations, threats, plans, goals, and constraints -- conceptual objects of a much higher level. In a C2 system built under the data paradigm, these higher-level conceptual objects are stored, if at all, as text strings, essentially uninterpretable by the system itself. As a result, the system can provide little active assistance to the decision maker.

Our paradigm is that a C2 system is a coordinated collection of symbolic processing subsystems that facilitate the command and control task: the synthesis of information from massive collections of data. The system components naturally include communications among people and machines, as well as data storage and access. But the data produced by these functions must be interpreted to produce a situation assessment, further interpreted to judge the validity and sensitivity of the hypothesis space that produced the assessment, and interpreted again to generate appropriate plans. Models, hypotheses and plans are all symbolic entities that can be manipulated by a properly designed computer-based decision aiding system.

There are several technological trends that are providing us with the leverage to exploit a symbolic processing paradigm for command and control. Chief among them is the maturation of our understanding of fundamental knowledge representation issues. As important, however, is the advent of real-time symbolic processor hardware and the large library of available software being produced in support of real-time symbolic processing, as well as

the emergence of a new systems development methodology that exploits sophisticated programming tools. It is the focusing of these forces on C2 problems that is creating the exciting possibility of a fundamental advance.

1.2 Resources

First generation real-time symbolic processors are microprogrammed versions of the machine technology available today. These machines emulate a virtual machine not too unlike current computers in design (as a community we are not at all agreed on any optimum design goals). However, the efficiencies accruing from optimizing the virtual machine to suit the programming language (usually LISP), combine with advances in circuit design and construction (such as VLSI) to result in an important improvement in the cost-performance trade-off for symbolic processing.

New technology is always something of a surprise, even with forecasts, analogues and simulations. The bigger the change the less able we are to predict the consequences. One rule of thumb used in the computing community is that a difference of one order of magnitude is not too difficult to assimilate, while a difference of two orders of magnitude is revolutionary. In very rough terms, the current set of prototype real-time symbolic processors run LISP about three to five times faster than it runs on currently available timesharing machines (e.g. PDP-10KA) and do so perhaps ten times more cheaply. Though the comparison is clearly not this simple, this combination puts us near the boundary of drastic conceptual change.

Just as important as computational speed and cost are two other features accompanying improved performance. First, the new

symbolic processors tend to be physically similar in scale to the "micro-computers" of the early seventies. That is, in physical size (a surprisingly important C2 parameter) they are likely to be a rack or less of equipment, and they will grow smaller with time. Second, these machines have very large virtual memory address spaces: 64 million bytes or more. These two features allow the new possibility of installing very complex programs in space-limited command centers.

There is another hardware aspect of the emergent symbolic processor systems that is very important for C2 applications: integral bit-map graphic display. Our experience indicates that a prerequisite to major advances in user-oriented systems is a flexible graphic display capability that has been carefully designed into the total system from the beginning. Bit-map graphics technology allows flicker-free display of complex figures. Most important is that the resolution of these displays is high, with current systems aiming at 1024*1024 pixels. Studies have shown that this resolution is good enough for situation display, while lower resolution displays are marginal.

A second important hardware feature is a local packet network interface. There are now inexpensive local packet-switched network implementations that have bandwidths between three and eight megabits per second, and higher-bandwidth networks are possible. These are being incorporated into the prototype symbolic processors so that they can communicate with centralized data and device resources, with other communications networks, and with each other. This kind of capability is a necessity when pursuing C2 applications.

To summarize, typical first generation symbolic processor hardware includes a fast, large address space virtual-memory computer directly executing a high-level language, an extremely

flexible display capability, and a high-bandwidth local communications link. An important goal of this research project has been to anticipate and explore the specific implications of this new resource for command and control.

The principle software resource on which this effort has relied is Interlisp [Teitelman 78]. A dialect of LISP, it affords all of the many desirable characteristics of that language: easy manipulability of programs, good facilities for handling complex structured data, control structures far more powerful than can be found in almost any other high-level language, and a large library of support functions. More than just a programming language, Interlisp is a carefully constructed programming environment. For example, it includes a program editor that "knows" about the structural properties of the language; a program source file updating system that keeps track of editing changes; debugging aids that allow selective tracing and breaking; a data record accessing package that facilitates data-independent programming; functions to aid optimization by selectively accumulating usage and timing statistics; and even a code analyzing and question-answering system for exploring and monitoring the access and control structure of large programs. Finally, the user interface to this environment has been augmented with a variety of aids such as automatic spelling correction, simple program error correction, and a code translator that supports a user-definable set of higher level programming constructs. The net effect is an amplification in programmer efficiency (for accomplished programmers) that enables a small team to achieve what would otherwise take a larger group a longer time to do.

Finally, since LISP is the language of choice for most of the AI community, there is a growing collection of potentially usable tools that can be built into larger systems. These tools

are all expressions of some aspect of the symbolic processing paradigm, and are the emergent results of the basic research into knowledge representation, reasoning mechanisms, and natural language understanding now being carried out in information science laboratories. Examples include semantic network memory systems; ATN parsers, grammars and grammar compilers for natural language handling; production-rule based reasoning and explanation systems; and interesting experimental systems for user interaction and knowledge extraction.

1.3 Methodology

The well-publicized failure of large-scale C2 systems to meet their goals, along with the failure of many large-scale non-C2 software systems, has led to the conclusion that there is something wrong at a basic level in the process of system development. The business community is now exploring a methodology that can best be described as "requirements definition first", but this methodology has been carefully applied in the C2 area for a long time with few discernible results. The problem is that domains such as command and control give rise to requirements that are generally ill-defined, changing, and closely interrelated to the evolving operational goals and developing state of technology.

Symbolic processing systems rely on deep models of the domain in which they work, with the most capable systems using very intricate, "realistic" representations. An example of such a model is that when interpreting sensor returns, what is considered normal behavior for an oil tanker may help resolve the referent of a satellite radar report. These models, in the C2 domain, require more and different information than is currently contained in any data base available, or found in studies of C2

information processing requirements. The only way that has been found thus far to successfully incorporate such knowledge into computer systems is to have some "expert" or experts in the domain involved in the process of creating the system. He or she guides the setting of goals and priorities and criticizes the developing system. A major flaw of the structured design approach in the C2 context is that the delay between the discussion of requirements and the first appearance of a system tends to be longer than the duty cycle of the "expert". When the system appears, it is usually delivered to a different customer with different problems.

We believe that it is becoming possible to use an entirely new systems development methodology that will alleviate these problems of focus and currency of delivered systems. This method is to rapidly build successive generations of systems, each being an incremental improvement on the previous one, at low cost and with close feedback from the intended user community [Sandewall 78]. The important aspects of this approach are the joint education of user and developer, the sequence of inexpensive approximations to find out what is important, critical, or desirable and the gradual collection of fairly small modules into a comprehensive system.

It should now be clear why the advent of real-time symbolic processors is so important. Previously, only two distinct paths existed in styles of system building. One was to utilize the full software and conceptual environment provided by symbolic processing and LISP to arrive at timely experimental software that tended to be too slow to evaluate reasonably. The other route was careful system definition, a long process of system building, and a usable resulting system that was obsolete before it was delivered. Real-time symbolic processors enable both

rapid incremental systems design and implementation that culminates in systems of sufficient power and speed for realistic evaluation.

1.4 Current Status of the Research

The course we have pursued with this research has been to utilize the incremental systems development methodology, applying appropriate resources, to meaningfully articulate the symbolic processing paradigm for command and control. This articulation requires much more than a report expressing notions that may be useful. There are no direct means for exploring and evaluating a paradigm per se. Instead we are using the indirect method of building experimental systems that inherently express the paradigm and then carefully searching for more general implications of both the experimental systems and the paradigm that produced them. Our original plan was to simultaneously pursue a number of interesting symbolic processing applications for command and control with several small experiments. At a much later point, a major attempt was to be made on some important C2 problem. As an initial experiment, we used a version of the RITA production rule system [Anderson 77] (written by R. Bobrow, in Interlisp) to run a tactical threat recognition and assessment aid (TECA) being developed cooperatively by the Naval Ocean Systems Center and the RAND Corporation [Brandenberg 77]. However, during the first quarter of the project we concluded we should not dilute our efforts on many small experiments, but settle instead on a focus of activity matched to our current awareness of the capabilities of symbolic processors and the needs of command and control. This decision was partly due to the continuing delays in the availability of symbolic processors outside of the developer's lab. Indeed, at the time of this writing, such systems are still not available.

The Massachusetts Institute of Technology Artificial Intelligence Laboratory's LISP machine, the most likely choice as a vehicle for this effort, did not become available this year as expected.

During the course of this work, Bolt Beranek and Newman completed an effort to microcode a modified PDP-11/40 to support Interlisp [Hartley 79]. This afforded us the opportunity to demonstrate the concept of real time symbolic processing in a stand alone environment; but since this system is limited in some respects (e.g. no floating point hardware or garbage collector), it is not a development resource.

In consultation with ARPA/IPTO program management we decided on a single effort to build what we have termed AIPS, for "Advanced Information Presentation System". This is a front-end system intended to be an intelligent display manager. It capitalizes on LISP machine architecture that provides a tightly coupled bit-map raster scan display terminal. It also satisfies a major need of command and control systems for a coordinated, application-independent information presentation mechanism. Finally, development of AIPS is strategic to demonstrating the "collection of symbolic processing systems" paradigm for C2, since it is the central element holding that collection together.

Representation of knowledge is the key to this kind of system. In fact, representation of knowledge in a declarative symbolic form is the only means we know by which such a system can be built. Accordingly, we have implemented a knowledge representation language called KLONE that is a structured inheritance network (SI-Net) system [Brachman 78a]. The general approach has been derived from research conducted at Bolt Beranek and Newman, Harvard, M.I.T., and the Xerox Palo Alto Research Center [Woods 75, Brachman 77a, Roberts 77, Bobrow 76]. SI-Nets are built out of conceptual nodes with rich internal structures,

using a carefully factored set of primitive relations. The relationship between two concepts can have considerable fine structure. This provides the necessary power to express how a concept can inherit the characteristics of other concepts.

Knowledge representation technology has evolved rapidly over the past few years and the KLONE system, which is epistemologically based, fully reflects the current state of the art. We have written a user reference manual for it [Brachman 78a] and there are several papers that describe the theoretical underpinnings of the system [Brachman 78b, Brachman 79]. It is implemented in Interlisp, and the KLONE system itself is evolving in response to our experiences.

We have developed an initial set of concepts for interactive presentation. This SI-Net can be found in Appendix A. While the presentation concepts are still evolving, the current set embraces view surfaces and projections of view surfaces, windows, clipping, and injections from world coordinate systems onto view surfaces. It also includes display forms such as circles, lines, and points as well as composite display forms such as pentagon, regular polygon and so on. The definitions for these include an initial set of manipulation routines. Each display form has attached procedures that know how to draw it, how to erase it, and how to find the distance from that display form to a given point.

The AIPS concept network described above has been embedded in an interactive graphics environment that offers a multiple window facility, albeit a rudimentary one. Currently, graphic output is via a bit-map, raster-scan display with a PDP-11 serving as the graphics processor. Graphic input is provided via a tablet and functions to discriminate the closest display form of a given type to the designated position. This allows for

goal-oriented interpretation of graphic input.

In order to drive the development effort, we have implemented two experimental applications of the AIPS concept: presentation of the status of the ARPANet and presentation of a simple, Over the Horizon (OTH) targeting situation. For the first application, LISP procedures were written that take information available from the Network Control Center at BBN and various sources of TENEX performance statistics. We then attached these to a KLONE description of an ARPANet display. The full logical structure of the ARPANet complete with IMPS, TIPS, hosts, and communications lines was represented in the network. The example, while not military in nature, did exploit a dynamic information source that is readily available and understandable.

The second AIPS application we constructed was a simple tactical situation display. For this example we built up concepts to describe the display of ships, missiles, aircraft, projected positions, missile paths, and "bends" in missile flight paths. In building this application, we experimented with the use of "icons" or small pictures to depict domain objects, and with graphic input menu selection. A major area of concern was how to represent the interdependencies among display forms so that changes in a form's position resulted in the correct behavior by its associates.

Finally, the above demonstration system was transported onto the PDP-11 Interlisp system, a prototype symbolic processor. To accommodate the displaced graphics routines, we re-implemented them in LISP so that the bit-map terminal would remain the primary input/output of the system. The Interlisp-11 is not quite complete, and the program still runs into troubles both hardware and software in nature.

We are now in a position to consolidate this year's work into a cleaner design, one that will better support a major expansion of the conceptual system. We are about to explore a higher level of presentation concepts such as desk top, chart, graph and table. One area that needs work in the near term is that of describing a presentation's reaction to changes in the environment. This includes devising presentations for doing alerting. Of immediate importance in this regard is to interface to a set of C2 knowledge sources that will provide a dynamic environment for AIPS. The continuation of this effort, however, has been moved to a new contract, and so this final report is merely an introduction to the next phase of an applied research effort.

2. THE USER INTERFACE PROBLEM

Current command and control systems, as well as all commercially available computerized MIS systems, include "application" programs: programs that generate some particular datum or decision aid. Each of these has its own input language (usually a simple command structure) and its own display management system. The input side has been heavily researched with concepts such as natural language, "programming by example", hierarchical menus, and others. On the output side, however, little has been done to separate the presentation of information from the generation of that information. That is, each application program displays information in the manner its particular designer thought appropriate, and in general the applications programmers control what the user sees.

This system design has two major limitations. The first is that the design is rigid. The output behaviors of the component systems are typically derived by studying some individual decision maker to see what he or she would like to ask and then programming in that set of queries. This is only a slight caricature; for example, the Tactical Flag Command Center (TFCC) system that the Navy is now developing can present some 200 different displays of information to the user; those 200 displays are spelled out exactly as to what they will contain. However, and especially in crisis situations, command and control users need to combine information from diverse sources and view the result from perspectives that are often unique to the situation at hand. These presentations will not have been anticipated, and the distribution of the display function throughout the C2 system obstructs their generation.

The second effect of each application program doing its own display management is that it is expensive. The input/output

portion of a program is invariably a major fraction of the code. It may take up to half the programming effort and perhaps even more of the design effort of a large and complex system. The Department of Defense spends a great deal on software development and that cost is increasing. Reduplication of a common and costly function is one of the reasons.

The solution of these problems lies in the view that the presentation of information is an understandable system function in itself, separable from other functions. AIPS, the focus of our current efforts, is intended to be a display management system general enough to act as the front-end for all the application programs in a command and control environment. Its purpose is to present information to the C2 system users, removing that job from the programs generating the information to be displayed. This centralization of display responsibilities provides a focus for efforts towards greater presentation flexibility, reduces the task of writing a C2 application, and consolidates the command structure for information display.

This concept fits very well into the current capabilities of symbolic processing technology. Knowledge-based systems are approaching a state of maturity that enables application to realistic problems. Knowledge representation semantics and inferencing mechanisms are becoming increasingly well understood. Limited universe-of-discourse natural language systems are being demonstrated often. All of these areas are involved in the realization of AIPS. The emerging generation of symbolic processors closely couple bit-map, raster scan graphics to a powerful programming language. Thus, the resources for intelligent display management are approaching the requirements, with good chances for successful application to an important C2 need.

3. PRESENTATION SYSTEM ARCHITECTURE

The purpose of this section is to provide a framework for more detailed treatment of AIPS' development. It is an overview of the internal structure of AIPS as it is expected to be when mature; it does not describe AIPS' current extent. Since AIPS is a knowledge-based system, this description concerns the different categories of knowledge important to AIPS, their interactions, and their functions. These collections of knowledge generally are not modular or isolable. The interactions among them are too dense, and the connections among them too rich for any of them to be fully understood independently. Rather, this factorization is an organizational ideal of the system's designers. Figure 1 below presents the architecture of a mature AIPS.

3.1 World Model

The first category of knowledge we have termed the **world model.** It is a collection of descriptions of the world that is to be depicted. These descriptions purely concern the domain of interest; they do not refer to what will be displayed, or how. Mainly, the knowledge at this level is represented declaratively. It includes not only concrete entities of the domain world, such as specific vehicles or geographic locations, but also generic and conceptual entities such as "rhumb line" and "order of battle".

The world model is continually refreshed by information sources external to the presentation system. These may include both sources of nearly raw data and sophisticated decision aids. The procedurally expressed knowledge at this level concerns how

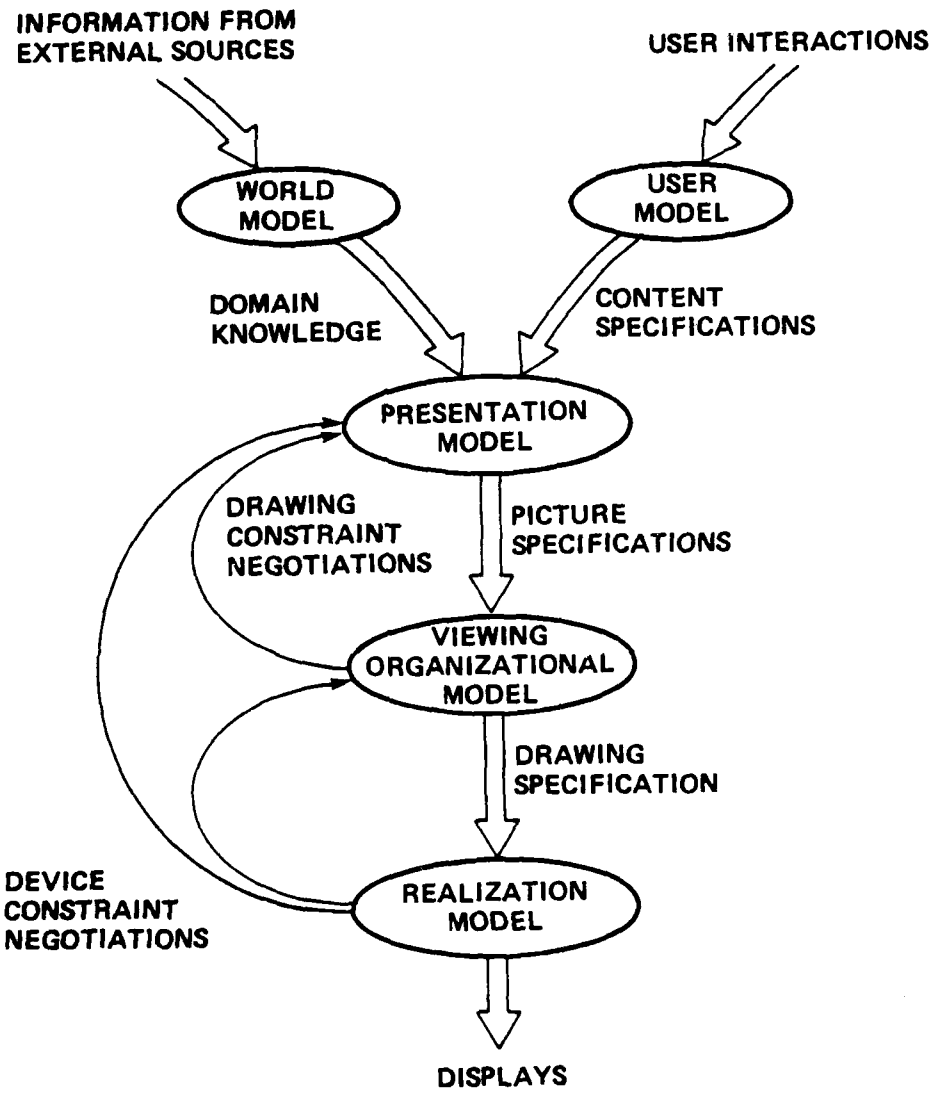

INFORMATION FROM EXTERNAL SOURCES
USER INTERACTIONS
WORLD MODEL
USER MODEL
DOMAIN KNOWLEDGE
CONTENT SPECIFICATIONS
PRESENTATION MODEL
DRAWING CONSTRAINT NEGOTIATIONS
PICTURE SPECIFICATIONS
VIEWING ORGANIZATIONAL MODEL
DRAWING SPECIFICATION
DEVICE CONSTRAINT NEGOTIATIONS
REALIZATION MODEL
DISPLAYS

Figure 1.

to translate communications with these sources into changes in the world model descriptions. In some sense, this processing converts data and information into knowledge by establishing connections with appropriate conceptual models. Another view of the world model is that it provides an interface to an indefinite number of widely varying information sources. Its declarative nature ideally suits that task because it facilitates control over the interactions among these sources. Redundant or conflicting information can be separately represented and reconciled explicitly.

3.2 User Model

The **user model** is the category of information about the system's end user. To begin with, this includes how the user's *preferences* differ from AIPS' default assumptions. Some examples are the user's desire that certain character fonts be used for various purposes, his dislike of a particular method for doing highlighting, his favorite formatting heuristics, and personal variations or extensions of standard symbologies. Such information can range widely in function within AIPS, so this part of the user model is really distributed among AIPS' other knowledge categories.

The user model proper consists of descriptions of the user and his task. Descriptions of the user as an individual might include items such as his reading speed, or his organizational connections within the C2 team. However, since our eventual goal is to arrive at a presentation system that works substantially without explicit direction, AIPS' most important knowledge of the user concerns his perceptual and decision tasks. These task models relate how the user's display requirements depend on the current state of the world model. For example, the fact that the

weather is bad enough to be a decision factor, or that the current operation is some phase of an amphibious assault can influence what the display for a particular task should contain. Thus, the function of the procedural knowledge at this level is to arrive at specifications for the content and purpose of the presentations to be made to the user. Interaction with the user, the current state of the world model, and knowledge about the user's tasks each enter into this process.

3.3 Presentation Model

The third important category of AIPS knowledge relates presentation function to presentation format. Here the transition is made from domain objects to viewable objects. This **presentation level** describes generic forms such as "map", "graph", "table", "legend" and "menu". These descriptions cover not only the structures of these forms in terms of lower level graphical entities, but also how structure and suitability depend on the perceptual task to be performed and the semantic content to be presented. The function of this knowledge is to convert content specifications into a sort of virtual picture, a description of the presentation's components and structure that refers to the domain objects to be depicted.

There is considerable interaction between this level of knowledge and the viewing organization and realization models discussed below. While procedural knowledge in the world model and user model is attached directly to the representational structure, on this level the procedural knowledge is an interpretive process that searches descriptions to match content and function specifications with generic presentation forms. This interpreter ranges over the viewing organization and realization models as well and is the primary mechanism for

interaction among the three levels.

3.4 Viewing Organization Model

The viewing organization model is the place where issues of layout and composition are dealt with. Activities such as scaling, clipping, and transformation are supported by the knowledge at this level. The important distinction between it and the presentation model is that here the presentation form is treated as a geometric and topological entity, without reference to semantic content. The descriptions at this level include concepts such as screens, display regions, coordinate system mappings and layout envelopes. These descriptions and the procedures attached to them convert the structural descriptions from the presentation level into detailed drawing specifications expressed in terms of composite display forms with discrete location.

Primarily, the knowledge at this level concerns graphic constraints. Many of these constraints are explicit characterizations of the human factors of graphic display. Some examples are such things as how to position labels to avoid clipping, the minimum acceptable spacing between the items in a menu, or the notion of one window being "close" to another. Others have to do with topological constraints, such as the behavior of "connected" display forms under various transformations, or the availability of unused display surface.

3.5 Realization Model

The realization model is the fifth and lowest level of descriptions in AIPS. Its function is to realize on the display device the composite graphical objects treated as atomic by the

viewing organization level. Most of the descriptions at this level concern such things as characters, points, lines, arcs and simple geometric shapes. The procedural knowledge attached to the descriptions tells how to draw and erase these entities in device-dependent terms. This dependency is expressed here rather than submerged within a library of device-independent drawing routines so that the system can fully exploit the differing capabilities of its display devices. Device capabilities are also represented declaratively at this level, so that this knowledge can influence the presentation planning and construction processes.

In order to prepare the reader for a more detailed discussion of AIPS' current conceptual network, the next two sections of this report describe the current BBN bit-map display and the KLONE knowledge representation language.

4. BIT-MAP GRAPHICS

4.1 Concept

Since the early sixties it has been accepted that a graphic interface to an interactive program can be more supportive than one based on typewriter-like terminals. In addition to the much wider bandwidth between user and program provided by pictures (a picture being worth many words), good selection of pictures can give the user the feeling that he is seeing program constructs directly. If the program's manipulatory devices (pointers, markers, buffers) are also presented in the picture, a sense of "handling" concrete objects can be provided. The resulting feeling can be that "what you see is what you get", a rich sense of immediacy.

Unfortunately, the cost of supporting interactive graphics has been prohibitive for all but a few special applications. With line-drawing graphics technology, high-speed displays are necessary for refreshing even moderately complex pictures fast enough to prevent flickering of the image. To do the necessary processing of the picture description in real time usually requires separate "display processor" hardware.

The recent advances in the technology of microelectronics are changing the economics of interactive graphics by making possible a new approach to the creating of pictures. In this approach, called bit-map graphics, one bit of semiconductor memory is dedicated to each position (picture cell; pixel) on the display surface. The picture is defined by setting to 1 those bits corresponding to pixels where the picture should be black, and to 0 those where the picture should be white. Multi-bit pixels can be used to drive grey-scale or color displays in a

similar manner. Relatively simple accessing circuitry can then be used to scan through this memory line by line creating a video signal to drive a standard (or high-resolution) television monitor. Thus, the full screen can be filled with information without separate processing facilities and without flicker. This capability has not been possible with earlier displays.

Unfortunately, this new graphics technique is not simply an improved version of older ones. While the paradigms of graphic interaction do carry over, the displays themselves force a somewhat different viewpoint on the designers. With older graphic displays, you moved a beam around; on bit-mapped displays, you make dots. Thus, bit-mapped pictures are composed of areas -- even lines and text characters will usually be more then one bit "wide". On line-drawing displays, the beam can pass many times over the same point on the display; in bit-mapped displays, the beam passes each point only once. Thus, where line-drawing displays are augmented by adding new lines, bit-mapped displays are augmented by replacing some information that is already "in" the display. So, where adding a line and then removing it again is easy in line-drawing displays, it is hard in bit-mapped displays, because the lost information cannot easily be regenerated. Finally, with bit-map graphics, the screen is full of information rather than being sparsely populated as before. This is raising new issues concerning the human factors of display format and heuristics for composing and "uncluttering" display presentations.

4.2 Current Hardware

Since a real-time symbolic processor with an integral bit-map is not yet available, we are attempting to simulate that environment with more conventional hardware. Our work is

currently being done on a DECSystem-20 and a remote experimental bit-map terminal called the BMG-11.

The BMG-11 graphics terminal is constructed around a DEC PDP-11/40. The bit-map memory and the display processor program reside here. The PDP-11 is connected by a 9600 baud asynchronous line to the DECSystem-20, which runs the TOPS-20 operating system. The AIPS software runs on the DECSystem-20, and interfaces to the display system via a package of display control functions written in Interlisp. To TOPS-20 and other programs running on the DECSystem-20, the display terminal appears as an ordinary terminal whose display behavior can be controlled by embedding escape sequences in the input stream. These escape sequences are intercepted and interpreted by the display processor program. The rest of the stream is displayed as text.

For input, the terminal has both an alphanumeric keyboard and a graphic tablet. These are connected to the unibus of the PDP-11. The output is via two video display monitors. These are driven by a video generator that takes its data from two banks (called "planes") of memory that are accessible either as a unibus device or as unibus-accessible memory. Each plane is 454 lines of 576 bits per line (about 1/4 million bits.) Each is connected (through the video generator) to one of the monitors, both of which run at a standard TV scan rate (525 lines, interleaved fields). One of the monitors is a relatively cheap ($300) General Turtle monitor, which uses a P39 (green) phosphor. The other is a high quality variable scan rate (up to 1500 lines) Conrac monitor with a P40 (white) phosphor CRT.

The video generator is the only piece of unusual equipment in the terminal. It was supplied by Symbolic Systems Inc. of Belmont, Mass. It consists of a controller board and two memory planes. The controller is a microprocessor that responds to

unibus requests and creates the video signal(s) through D-to-A converters. Every other memory cycle is dedicated to video generation and the remainder to the unibus.

When the bit-map is part of the PDP-11 address space, all of it is directly accessible by the display processor program. When the memory is set up as a unibus device, it appears as three registers: a control register, an address register and a data register. The control register specifies which plane is being addressed and whether or not the video signal should be inverted on output. The address register specifies which (single) word of memory should appear in the data register (addresses are relative to 0 at the top left corner of the screen). The data register is used as any normal PDP-11 memory register: that is, bits can be MOV'd or OR'd or XOR'd to memory.

4.3 Functional Characteristics

All output to the bit-map terminal is expressed relative to a display region: a rectangular display area with its own coordinate system whose boundaries are enforced with clipping. There are two possible views of each display region: text display and graphics display. The BMG-11 display processor program currently supports a maximum of 128 such regions. At any given moment there are two possible destinations of output going to the BMG-11: the current terminal (TTY) region and the current graphics region. Ordinary text sent to the terminal will go into the current TTY region; graphics sequences are executed relative to the current graphics region.

Each active display region has a current graphics cursor location. As a TTY region it also has a current print cursor location. Each region has a mode of display, one of: ADD (OR

bits into the map), REMOVE (AND the complement of the bits into the map), FLIP (XOR points into the map), or OVERWRITE (like ADD, except that for characters the entire character cell including the background is smashed into the map).

Each region has its own font: characters put into the region, either via TTY or graphics, use this font. Each region also has two other attributes which are meaningful only when the region is used as a TTY region. One is a scrolling characteristic that tells what to do when the character stream is about to fall off the bottom edge of the region. The other is a background characteristic that tells what grey pattern should be used in resetting the region background.

Graphics operations include: moving to a position, drawing a point, drawing a straight line, putting up some text, painting a whole region grey, filling a region with the contents of another region, setting the various characteristics of the regions, and setting which regions are to be considered the current graphics and TTY regions. TTY operations are effected simply by sending a stream of characters to the terminal as normal output.

Some miscellaneous functions are provided to permit inverting the video on the monitor (white on black, or black on white), and for diverting the output going down the graphics stream to printing functions which type out on the terminal the sequence of graphics operations being executed. No memory of the state of the bit-map display is maintained by the functions in the display control package. Some state information, such as the characteristics of the currently active display regions, the screen size of text fragments, etc., can be retrieved from the display processor program. An exhaustive description of the display control package is given in Appendix B.

5. KNOWLEDGE REPRESENTATION LANGUAGE

This chapter discusses the KLONE knowledge representation language used to implement AIPS. Section 5.1 presents a theoretical and historical framework for understanding KLONE's contribution to the current state of the art. Section 5.2 gives a capsule description of KLONE's representational primitives. Subsequent sections discuss various features of KLONE in detail. Readers who are less interested in the detailed examples of AIPS' operation given elsewhere in this report may prefer to read only section 5.2 of this chapter, or to skip this chapter of the report altogether.

5.1 Theoretical Basis

Perhaps the most difficult task facing us when we try to represent some segment of our knowledge is our very first: at what level of abstraction do we begin to express this knowledge? When designing data structures to be manipulated by a single-minded program, we find it easy to determine the "representational grain". But when trying to capture the details of our knowledge about a particular area of expertise in order to support a general cognitive system whose goals in manipulating the structure we cannot determine in advance, we are at a loss to determine the conceptual size of the units of our knowledge. If the medium is predicate calculus, how do we determine the most useful set of predicates? How detailed should we make the primitive predicates so that we support all distinctions that our reasoning system will need to make, yet avoid a proliferation of useless (and perhaps ontologically meaningless) epistemological minutiae?

Besides problems with the grain size of a representation, we

also encounter problems in determining the basic types for our conceptual objects, especially in logical formalisms like predicate calculus. For example, does conceptualizing the predicate, PERSON(X), force me to think of "person-ness" being attributive rather than of persons as objects? And when and where does this make a difference?

Where will we look for help? The obvious place is to the representation language used to encode the data. Each such language provides for its user (the knowledge engineer) a set of object types and syntactic conventions, which together suggest how to factor concepts of the domain. That is, by adhering to the representational conventions of a language, we have certain decisions made for us -- the language embodies the set of distinctions that its designer has deemed meritorious, by prespecifying the types of entities and relationships that can be encoded and the level of detail of structure that can be expressed. The primitives of a language implicitly embody the epistemology which the language's author believes is the way to look at the conceptual world.

To a large extent, the last ten years' representation languages have had their epistemologies all too implicit. In particular, "semantic networks" have achieved great popularity in systems that deal with natural language information, yet only very recently has the adequacy of these representations come into question [Woods 75, Brachman 77b, Brachman 77a]. Each version of the semantic net had implicit in it a set of knowledge-factoring principles that were given little explicit acknowledgment. In some cases, logical predicates and connectives formed the basis level of representation while others allowed both logical constructs and cases. Still others expressed the belief that very high-level primitives -- those of a natural language itself -- were the only kind sufficiently vague to allow us to properly

factor knowledge. At least in the case of logical networks, formal adequacy was an understandable and achievable goal, and eventually did become an explicit target for representation system designers. But in most cases, it was not clear what the representational theories were that underlay the semantic net data structures.

In order to help understand the implications of the particular sets of links and node-types offered as "built-in" by semantic net schemes, we will briefly present a set of five abstract levels of representational primitives. The level that characterizes a representation scheme (independent of the adequacy of the particular scheme) has a strong impact on the way knowledge will be factored in order to be expressed in that language, since its primitives represent the finest distinctions that the language is capable of expressing. These levels range from the mechanistic implementation level through the intermediate logical, epistemological, and conceptual levels, to the most information-laden language level.

The first view of semantic nets that we will consider is the one that takes them to be associational data structures, with no representational import. Very few systems have been proposed that can be considered as purely of this level (the earlier work of Shapiro [Shapiro 71] is perhaps the best example). The constructional primitives of such schemes are pointers and atoms, and can be used in any way the knowledge engineer desires. No semantics are ever claimed for the elements of this lowest level -- the most significant claim that is made is usually about the indexing facility provided by the associational links.

The first jump to primitives with some representational import is usually made at the level of logical elements. The principal proponents of logical networks [Schubert 76, Cercone

75a, Cercone 75b, Hendrix 75a, Hendrix 75b, Shapiro 75, Shapiro 77] generally argue that their networks provide real advantages over predicate calculus representations, including that they seem more natural and understandable. The semantics of constants, predicates, and propositions is relied on for networks that express the same structures as can be expressed in linear predicate calculus forms. When primitives in representation languages take on this logical form, the language becomes an alternative surface form for predicate calculus (parentheses and adjacency are replaced by pointers) -- usually with some added "indexing" facility. The logical level is the one level of network representation that comes into direct contact with classical notions of semantics, and the only level wherein claims of adequacy are not made solely on empirical or intuitive grounds.

One concern of advocates of languages at "higher" levels is that the primitive elements of logical languages are too "small" to be easily compounded into meaningfully large representation structures. While predicate calculus is logically adequate, there is reason to believe that knowledge representation can be done with more communicative power by resorting to a set of primitives that (in the right context) are not logically primitive. This is the substance of the epistemological level.

The focus at the epistemological level shifts away from predication, and onto "objecthood". The difference between logical level and epistemological level paradigms is subtle, and while it might at first appear to be an arbitrary one, we believe it to have some significance for the shape of the next generation of representation languages. The primary difference is the shift from an orientation toward attribution to a concern for the internal structure of perceived objects. The focus on objects leads to investigation of the functional roles to be played

within the object (often referred to by their implementation-level counterpart's name, "slots") and the kinds of structured inheritance relations that can exist between objects.

For pure conceptual level formations, the central question is what particular concepts and cases are to be taken as primitive. While the concern for concept-structuring epistemological primitives is a recent development, one of the oldest trends in semantic nets is that of providing primitive concepts and relationships. Perhaps the strongest influence on work at this conceptual level is the work of Schank [Schank 72, Schank 73a, Schank 73b, Schank 74], in which a small set of primitive ACTs and case relations is proposed. In a system based on conceptual dependency, it is claimed, any concept can be broken down into a canonical complex of the primitive actions and cases, and inferences then drawn from the primitives.

An epistemological formalism, on the other hand, provides the facility for defining an open-ended set of basic concepts and cases, thereby implicitly assuming that while the notion of "case" (role) is primitive, no particular case necessarily is. These two views have different psychological and theoretical implications, some of which might be empirically testable.

Finally, we might consider an approach in which cognition is not possible without language. This commitment -- to take seriously the Whorfian hypothesis that "a person's language plays a key role in determining his model of the world and thus in structuring his thought" -- is the founding principle for OWL [Martin 77, Szolovits 77]. In OWL (and presumably other formalisms like it), there is a small set of structuring relationships that tie together language-specific concepts. These relations are small concessions to the need for a syntax

for the language, and are a bit problematic to analyze. Everything in an OWL network is essentially primitive with respect to any new pieces of information. Once new information is added, the primitive set is changed. Thus, this highest level provides the expressive power of English in computer language, at the expense of a certain feeling of "it all depends" and possibly begging the question of the language's semantics.

Recently, several representation language efforts have proposed, as primitive, structuring relations for creating non-predicative conceptual objects. The subject is becoming that of what is thinkable, rather than of what is logically possible. Evidence for these epistemological primitives is being taken from perception and ontology, with emphasis on what might be "natural" for a perceiving, plausibly reasoning system. This quest for a set of epistemological primitives is based on two general requirements: 1) the need for a set of concept-structuring syntactic elements at a high enough level to make the factoring of general conceptual knowledge easy, perspicuous, and naturally reflect the way that we think about the world, and 2) the requirement that such a factoring still have a clear, precise, and formal semantics.

Whereas logical languages like those described in [Schubert 76, Hendrix 75a, Hendrix 75b] satisfy well the second requirement, there is some debate as to their amenability to "natural" conceptions of the world. Further, the predilection of logical languages for predication may also be inappropriate. In contrast to logical level languages, those of the conceptual level seem to proffer structured conceptual objects -- but at the expense of an unwritten pledge of allegiance to certain predetermined conceptual cases. Also, the semantics of such languages are suspect -- or at least rarely discussed.

The knowledge representation language we are developing (in cooperation with Woods' natural language research group at BBN) takes an intermediate approach: structured conceptual objects are its raison d'etre, but it does not presuppose any particular objects or case relations. Thus, it is purely a construct of the epistemological level. While research is continuing on this language -- KLONE -- it already contains a significant portion of the requisite representational apparatus. KLONE is currently implemented on a TOPS-20 system as a set of Interlisp functions, which provide access to a KLONE data base implemented as user-defined data types.

5.2 Primary Contributions of KLONE

KLONE is based on the idea of "Structured Inheritance Nets" [Brachman 77b, Brachman 78a], wherein descriptions of structured conceptual objects are organized in lattice-like networks, with inheritance between descriptions being carried by structured cables.

There are two principal participants in the concept structure: Roles and Structural Descriptions. A Role has internal structure that describes a conceptually identifiable subpart of a Concept. The Role is intended to capture the intentional description of a role filler in context -- it is a place, for example, to hang information about the owner of a particular Volvo, even if the identity of that person is not yet known (or, if known, it is a place to attach separate statements about the person as a car owner, as distinct from statements about the person as a home owner, parent, etc.).

Structural Descriptions (SD's) take the set of conceptual subparts and express the structure of the interrelationships

among them. These relationships give the Concept its "gestalt" -- they, for example, differentiate between verbs whose case frames are identical, or express how a stack of bricks is different from a pile of the very same bricks.

This internal structure of Concepts gives the **inheritance hierarchy** its structured nature. Concepts, as structured wholes, can be related to other Concepts by **Inheritance Cables**, whose internal **Wires** pass the Roles and SD's from more general Concepts to others which subcategorize them. This explicit Role/SD inheritance avoids the problem of "slot" naming confusions common to most network formalisms.

KLONE allows one to create **Individual Concepts** that are descriptions of individual objects and to relate such Concepts to definitional, **Generic Concepts**. Further, assertional connections are expressed by attachment of *Individual Concepts* to **Individual Constants**, which stand for previously identified (or potentially identifiable) extensional objects. This way the dichotomy between assertion and definition is kept clean, and the intentional world of the lattice is kept homogeneously descriptive.

The final critical feature of KLONE is its bipartite "attachment" mechanism. To any KLONE Concept, Role, SD, or Cable, a **metadescription** can be attached. Metadescriptions treat entities qua entities, and express knowledge about knowledge in KLONE itself. In addition to the attachment of declarative representational structure, the attachment of procedures (interpretable by the KLONE interpreter) is a built-in feature. Such procedures are written in the language of the interpreter, and are invoked in particular prespecified situations.

In the sections that follow, we will discuss the most

important KLONE entities in more detail. The reader is cautioned that this discussion is neither complete nor current. Its purpose is to reflect the state of development during the reporting period (we are now working with a substantially improved version) and to prepare the reader for a detailed discussion of AIPS' constituent concepts. For a more complete discussion of KLONE, consult [Brachman 77b, Brachman 78b] or [Brachman 78a].

5.3 Internal Generic Concept Structure

Descriptions of structured conceptual objects appear in KLONE as Generic Concepts. A Generic Concept has the appearance of a description of a single, prototypical member of a conceptual class, but, in fact, can be satisfied by an arbitrary number of differing, individual descriptions of particular members. Generic Concepts act like intensional entities: they can be manipulated and reasoned about without regard to the extensional ("outside world") objects (if any) of the class described. Relations between Generic Concepts, and among their internal parts, are definitional -- they make no claims about the "outside world", per se.

There are two varieties of epistemological subparts of KLONE Concepts: Roles and Structural Descriptions. Roles represent the subpieces of the Concept that can be talked about in their own right -- these express the "slottedness" of conceptual objects that is prevalent in "Frames", KRL units, MDS templates, case frames, etc. The Generic Roles of a Concept express its perceived generalized attributes, including its physical parts (if applicable), and other qualities important to the conceptual complex. Structurally, a Generic Role interrelates three particular kinds of information:

1. the functional role that the conceptual subpiece will play vis-a-vis the Concept as a whole;
2. a description of the particular kind of entity that can potentially fill that functional role;
3. set-oriented information relevant when more than one entity can fill a given role.

A Role is unique to its associated Concept -- descriptions of fillers and fillers themselves are independently identifiable Concepts, but Roles are not. This makes the Role an obvious place to tie information about a filler in its context, that is, information about some entity's participation in a structure, independent of its own internal structure -- or even its existence. In Generic Concepts, Roles are places to talk about agents of verbs, elements of task forces, ranges of weapons, etc., independent of any particular fillers.

The current KLONE representation of Generic Role structure is detailed in Figure 2. A Role cannot exist without having some Concept as its context, and thus the epistemological connector called **RoleDef** must always be present. The **RoleName** connector allows an arbitrary, user-specifiable name to be associated with the complex of relationships associated with the Role by the set of pointers. RoleNames can be duplicated at the user's convenience, since they are only meaningful to him or her. The **ValueRestriction** primitive ties a description of legal potential fillers to the Role. It points to one or more other generic descriptions that must be satisfied by a Role filler in and of itself. That is, the ValueRestriction is a description that applies to a filler in its own right (i.e., describes its intrinsic characteristics), as opposed to those descriptions derived by virtue of its involvement with other Concepts.

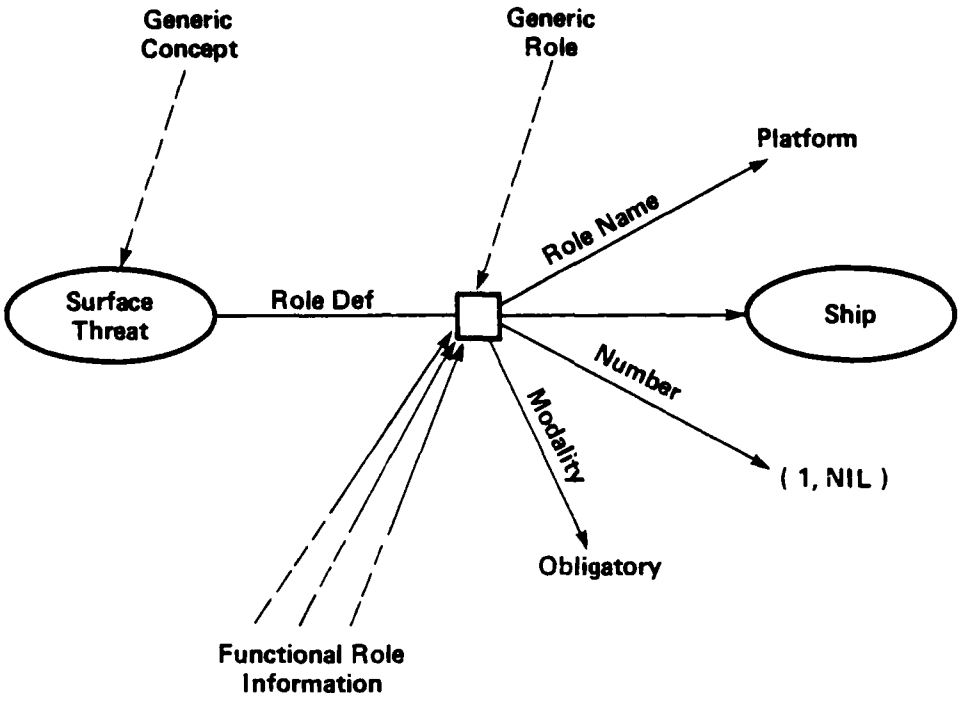


Figure 2.

Finally, the Number facet of a Role expresses the limitations on the cardinality of the set of fillers of that Role. The current KLONE format allows only the specification of a range of values, with either the maximum or minimum (or both) possibly being "don't care".

While many of the conceptual subparts of an object can be reified, and talked about as "cases", "parts", or "attributes", there are relationships among these that are not referenced explicitly. The relationships are nevertheless critical to the Concept's description, as they provide the meanings for the cases, etc. Without such a structural "gestalt", for example, all verbs with identical case frames would be indistinguishable. The description of how the role fillers interact is as much a part of a Concept as are the descriptions of those fillers in and of themselves.

KLONE provides a set of epistemological structuring primitives for creating such relationship descriptions. Each Concept is allowed to have a set of Structural Descriptions (SD's), each of which comprises a complex of **Parameterized Individual Concepts** (ParaIndividuals). A ParaIndividual is a copy of a relational Generic Concept that is referenced in some other concept to show how more than one role filler interrelate. The ParaIndividual (like the Role) is unique to the Concept (in fact, the SD) in which it appears.

In Figure 3, the dashed line has been put in to suggest the scope of the "internal" structure of the Concept SURFACETHREAT (this partition has no explicit counterpart in KLONE -- the "scope" of a Concept can be determined simply by collecting a formally characterized subset of its epistemological relations). Note that Roles as well as ParaIndividuals occur within the Concept. While Roles stand for single objects, and ParaIndividuals usually for relations, both are in a sense "parameterized" by the Generic Concept in which they occur. When an Individual Concept is described by some Generic Concept, its corresponding Role fillers and SD relations are firmly determined by the "template" structure in the generic.

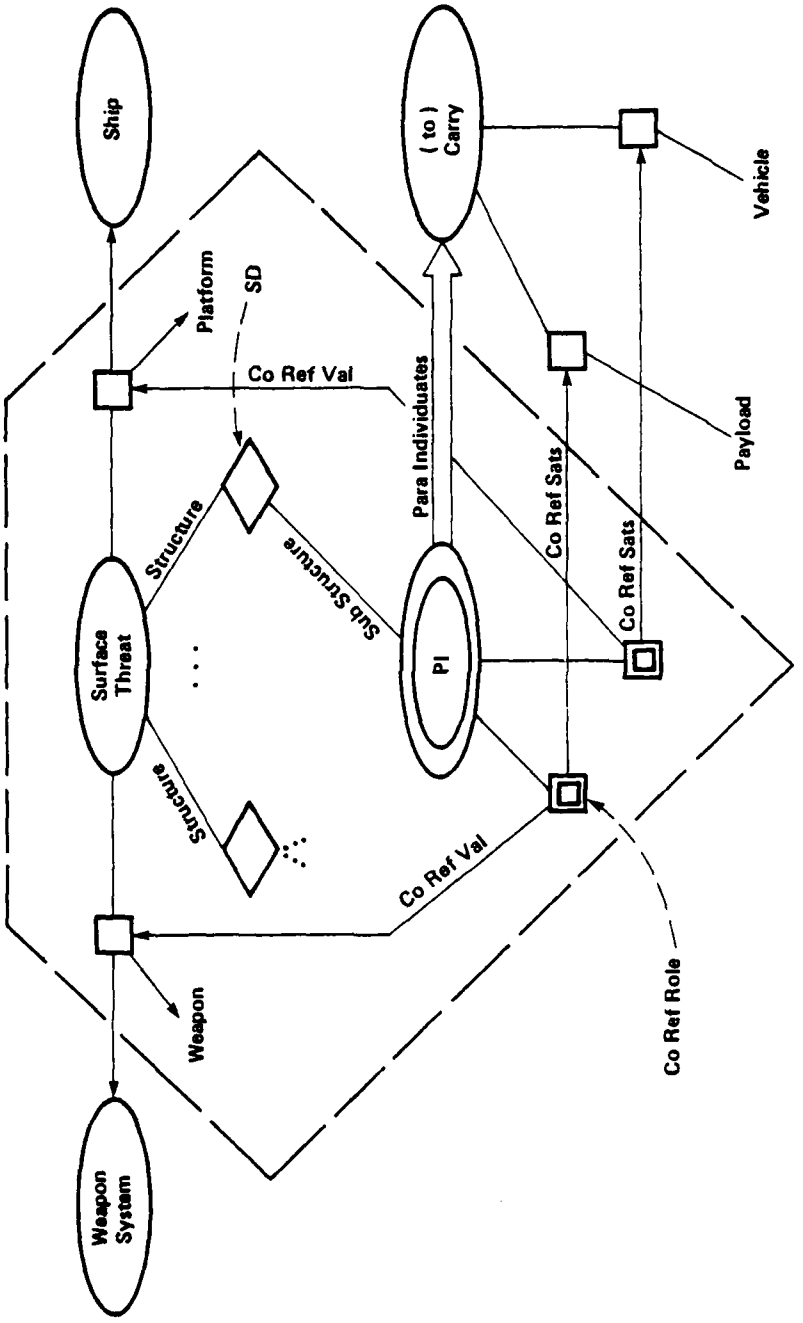

Ship
(to) Carry
Vehicle
Platform
SD
Co Ref Val
Payload
Para Individuates
Co Ref Sats
Co Ref Sats
Structure
Sub Structure
Surface Threat
PI
Structure
Co Ref Val
Co Ref Role
Weapon
Weapon System

Figure 3.

For example, within the single SD of the Generic Concept SURFACETHREAT is the ParaIndividual PI. PI is a version of CARRY that is unique to the Concept SURFACETHREAT -- that is, any structural manipulations of the Generic Concept CARRY would affect all other Concepts that were in some way dependent on CARRY, but structural changes to the ParaIndividual PI would affect no Concepts dependent upon CARRY. In this figure, the relationship of the ParaIndividual PI to its defining Generic Concept CARRY is indicated by a Structured Inheritance Cable labeled "ParaIndividuates". This Cable indicates that PI has the identical internal structure to CARRY, except that where CARRY has two Generic Roles, PI has instead two Coref Roles.

Coref Roles stand in a similar relationship to Generic Roles as ParaIndividuals do to Generic Concepts. What the ParaIndividual and its Coref Roles mean is the following: in any particular Individual Concept descendant from the Generic Concept in which the Coref Roles occur, there will be a particular instance of the paraindividuated Concept that is relevant to that individual only. Each Coref Role will have its filler in that individual be coreferential with the filler of the Role indicated in the generic by the CorefVal link. For example, in any particular SURFACETHREAT, P, there will be an individual CARRY relationship existing between P's own Platform, and P's own Weapon. That is, for something to be a SURFACETHREAT, it must have a Weapon that is a WEAPONSYSTEM, a Platform that is a SHIP, and that Platform must CARRY that Weapon.

5.4 Aspects of Structured Inheritance

With each KLONE Concept comprising a set of structured Roles and SD's, the notion of "inheritance" that is the mainstay of most network formalisms becomes a complex issue. To express the

description of a Concept in terms of a more general one, we cannot merely connect the two with an "ISA" link -- we must account explicitly for how Roles and SD's of the more general Concept (the super-concept) are related to those of the less general (the sub-concept). This is particularly critical when Concepts are allowed to have more than one super-concept: Roles "inherited" from one super-concept must not interact inadvertently with those from another.

The fact that Roles and SD's are explicitly addressable structures gives KLONE the leverage it needs to deal with inheritance in a clean, powerful way. The basic mechanism for inheritance is simple: a Concept inherits all Roles and SD's intact from each of its super-concepts through a Structured Inheritance Cable (i.e., one Cable per super-concept). With no altering structure at the sub-concept, Roles and SD's of each super-concept are considered to exist as independent, identifiable entities, even if RoleNames coincide. The fact that Roles are not simply their names keeps any coincidental conflicts from arising, a problem that has plagued most network systems.

Figure 4 illustrates the simplest cases of structured inheritance (SuperConcept Cables are represented by broad arrows). In Figure 4(a), the Cable C1 passes Roles R1 and R2 and SD's S1 and S2 from the Concept ASCM to the Concept HARPOON -- that is, to all interpreter routines accessing the Roles of HARPOON, it appears as if that Concept is the direct owner of R1 and R2. In this case of no modification of any of ASCM's structures, the Cable acts as a "short circuit" between the two Concepts, and HARPOON is virtually the same Concept as ASCM (see [Fahlman 77]; note also that this is, taxonomically speaking, a useless connection -- there is no difference between the two Concepts). Figure 4(b) illustrates the same kind of inheritance for multiple super-concepts. To all Role-accessing

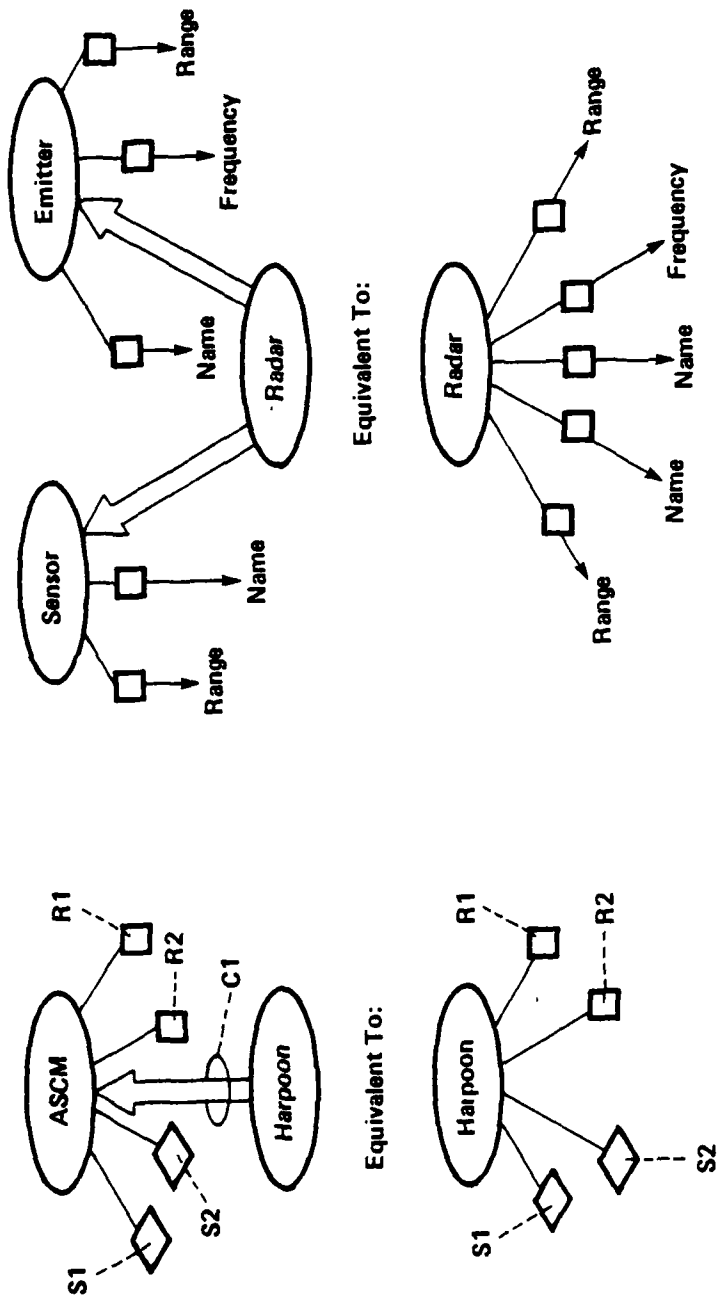

Emitter
Range
Frequency
Name
Radar
Sensor
Name
Range
Equivalent To:
Radar
Range
Frequency
Name
Name
Range
Fig. 4B
ASCM
R1
R2
C1
Harpoon
S2
S1
Equivalent To:
Harpoon
R1
R2
S2
S1
Fig. 4A

Figure 4.

processing routines, Concept RADAR looks as if it were the direct owner of five independent Roles, two of which happen to have the associated RoleName "Name" and two of which happen to have "Range" as their RoleNames. As far as KLONE is concerned, no connections are implied by these coincidences. One Range of RADAR is by virtue of being an emitter, the other is by virtue of being a sensor. That is, the Roles are associated with the Cables.

The case of the Name Role is interesting, in that one would not expect a radar to have two independent names -- presumably both Name Roles arise from a common super-concept. Thus, a Role-joining mechanism is necessary to prevent propagation of ghosts of inheritances past. This brings us, then, to a discussion of the various epistemological relations Roles can have with "super-roles".

As suggested by the above examples, while Roles may be descended from those in super-concepts, it is not always useful for a Role to be an exact copy of its source. In order to make sub-concepts more specific descriptions than their super-concepts, we frequently need to modify the Role descriptions of the sub-concept to make them more tightly constrained. In such a case, a Role is still "inherited", but some part or parts of it are to be altered in the process.

Where the restriction on the definition involves a tightening of the ValueRestriction to a more specific description, the descendant sub-concept has an explicit Generic Role for each Role that is being modified, with an epistemological connector explicitly between it and the Role being modified. These component wires of the inheritance Cables are labeled "Mods", to indicate the type of change, in this case, an overriding of each piece of the Role that explicitly recurs in

the sub-concept. The meaning of "Mods" is that the indicated Role is inherited as a virtual copy, with each epistemological connector (except RoleName) that appears explicitly "overwriting" the corresponding one inherited in the copy.

Another inter-Role relationship is that of ValueRestriction satisfaction. Satisfaction sets up a binding of a Role to a particular value; that is, it allows a Role to be filled. The Role-binding pair is captured in KLONE by a different kind of Role than the Generic Role, which intensionally represents a set of potential bindings. Such a Role is called an **Instance Role**, and it simply represents the correspondence between the filler and its defining Generic Role. Figure 5 illustrates the use of Instance Roles to fix the values of certain parts of Generic descriptions. Once an Instance Role occurs in a chain of Concepts, it can no longer be modified (no epistemological connectors can attach to it from "below"). In Figure 5, this means that any descendant of S-3A must have the particular jet engine, GE-TF34, as its propulsion system Role filler. The two parts of Instance Roles are indicated by **Sats** connectors to Generic Roles, and **Val** connectors to fillers.

A third type of Role "inheritance" relation is differentiation, wherein a Role which expects more than one filler is expanded into a set of sub-roles. Figure 6 illustrates how KLONE allows such a Role to be differentiated into sub-roles In the figure, the **Diffs** link stands for the epistemological differentiation primitive. The Concept of a SHIP has three of its own Roles, each of which is expected to have one filler of the type specified as the ValueRestriction. Each of the Radar, EW, and Sonar Role fillers is still considered to be a sensor, but now has a distinct Role of its own. Roles created by differentiating Generic Roles of a super-concept are normal Generic Roles, with their own Number facets and

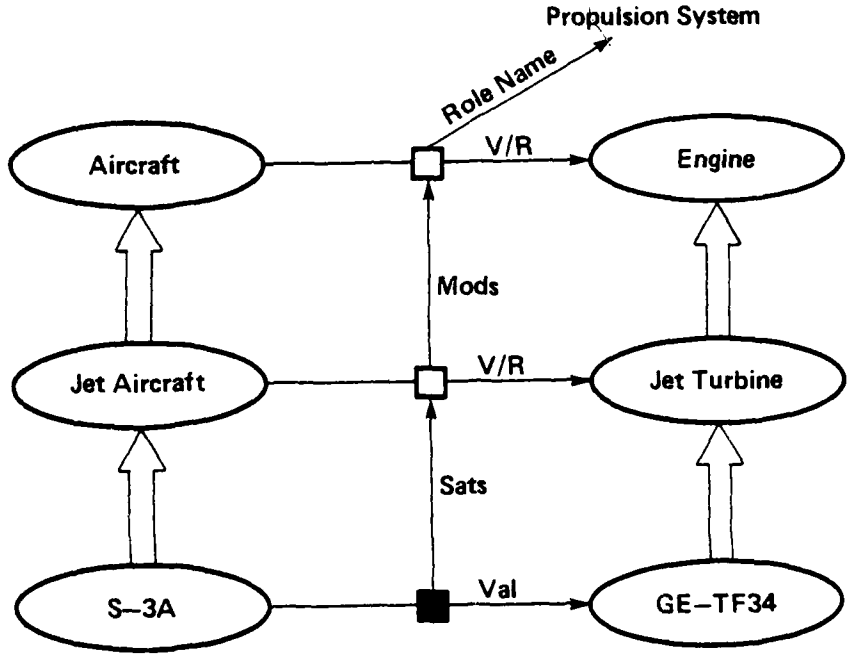


Figure 5.

ValueRestrictions. They can be further modified, differentiated, or satisfied.

The explicit connections between Roles and their sub-roles are the Wires running through the Structured Inheritance Cables. Each type of connector has a distinct meaning, and a formally specifiable set of inheritance rules.

"Sats" expresses the filling of a Role, in which case, the ValueRestrictions of the super-roles are expected to be satisfied by the filler, the Number facet of the super-role cannot be violated by the set of satisfiers, and the RoleNames applicable

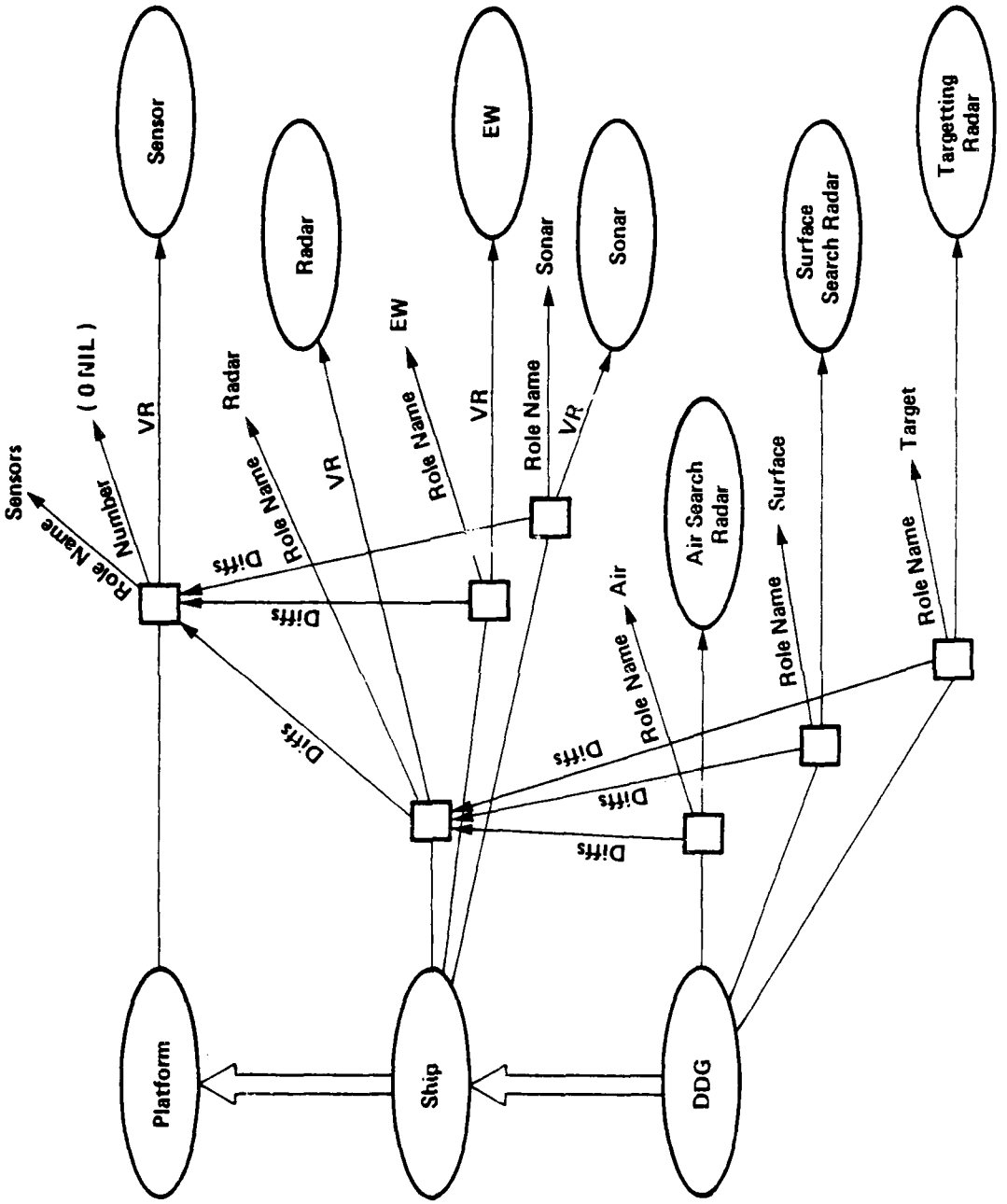

Sensor
Radar
EW
Sonar
Sonar
Surface Search Radar
Targetting Radar
Air Search Radar
Platform
Ship
DDG
VR
(0 NIL)
Number
Sensors
Role Name
Radar
Role Name
VR
EW
Role Name
VR
Sonar
Role Name
VR
Air
Role Name
Surface
Role Name
Target
Role Name
Diffs
Diffs
Diffs
Diffs
Diffs
Diffs
Diffs

Figure 6.

to the filler are taken from the defining super-roles. "Mods" makes the sub-role a modifiable duplicate of the super-role: the Number facet and ValueRestrictions of the parent are taken directly, unless overwritten with a local restriction. "Diffs" expands a general Role into more specific sub-roles; therefore, each sub-role is expected to play the part described in its super-role, but does not supersede it (in the "Mods" case, it is as if the super-role has been absorbed completely by the sub-role). The immediate effect of this is a default Number facet of (1 1). Notice that, in all cases, RoleNames apply universally down the inheritance chain -- given the intent of Roles, one would not expect to try to change one Role into another in the middle of the lattice.

5.5 Individuals and Individuation

Generic Concepts in KLONE, as stated earlier, are descriptions that are to be applied to individuals. One can join many super-concepts to make up a complex description -- one that may, in fact, be so complex that it could be considered to apply to only one individual in the universe. This, in some sense, allows us to "multiply describe" an individual in the world outside of the machine, and appears to allow us to focus on a single individual. But neither is quite the case.

Individuals, and descriptions of them, are generally problematic in knowledge represention languages. In KLONE we have chosen to distinguish carefully between the internal conception of an individual object (outside of the machine) and descriptions of individuals. A KLONE entity called an Individual Constant is created to stand directly for some object (concrete or abstract) when it has been concluded that one exists. This type of representational entity has no internal structure as far

as KLONE is concerned. An Individual Constant is merely a place to attach descriptions that are meant to refer to the same real-world object. That is, the Individual Constant, while abstractly "standing for" some real entity, is concretely for the machine a locus of description coreference.

An Individual Concept looks and behaves much like a Generic Concept. It inherits Roles in the same manner, through an **Individuation Cable**, which is similar to the normal SuperConcept Cable. However, an Individual Concept is required to be uniquely determined by its super-concept plus the specified values of its Roles. Another restriction on Individual Concepts is that they cannot be further subcategorized. They are "leaves" hanging off the bottom of the lattice. Finally, the transition from ParaIndividuals to real, individual relationships is made through the Individuation Cable. An Individual Concept inherits not just the SD's as specified in its parent Generic, but fully individuated versions of them with Instance Roles taking the place of Coref Roles, and the corresponding values for the individual filling those Instance Roles.

Individual Concepts and Individual Constants are very important for reasoning within the ontology of objects. For example, if one were to find that the same Individual Concept described two different Individual Constants, he would be forced to conclude either that what he thought were two individuals was in fact one, or that the description was wrong in one of the cases.

5.6 Metadescriptions and IHooks

In many of today's representation languages, there is a way for the knowledge base designer to go directly to the language in

which the system is implemented (e.g., LISP) in order to express certain facts or associate certain procedures with network structures. Such "escape" mechanisms are used either when the knowledge to be expressed is too complex to be represented in the network itself, when knowledge about the network itself is to be encoded, or when certain procedures are to be triggered by operations on the data base. With the work of Brian Smith [Smith 78], the epistemological import of "procedural attachment" is now much clearer. There are, according to Smith, two different types of attachment that are most often confused under the guise of "procedural attachment": 1) "meta-description", wherein knowledge about knowledge is expressed in the same language as the primary knowledge (e.g., KLONE itself); and 2) interpretive intervention, in which direct instructions to the interpreter are expressed in the language that implements the interpreter itself.

In the case of meta-description, the interpreter is being asked to make a type or level jump when processing a Concept. Meta-information is information about a Concept (or Role or SD) as a formal entity, and is not information about the thing(s) that the Concept describes. To support this kind of information in general, KLONE provides an epistemological primitive that ties a metalevel Individual Constant to a formal entity in the network. It allows us to talk about that entity as a "real" individual. This link is called a **metahook**, and it can attach to a Concept, a Role, or an SD. Descriptions of various sorts can then be attached to the Constants, thereby describing the individual formal entities.

Metadescriptions can be used for various purposes. One use of them in the current KLONE system is to express "default" fillers for Roles. Smith [Smith 78] points out that default information is basically advice to the reasoning mechanism, rather than basic epistemological structure. This is reflected

in KLONE by the use of meta-description. Notice that with defaulting being metadescribed, it is possible to specify a functionally determinable value instead of a single fixed one, as a default. A description of where to find that value would be expressed in KLONE itself rather than tied by an assertion connector to an Individual Constant.

KLONE provides another kind of hook, the **interpretive hook** or **IHook**, for attaching interpreter code directly to a Concept, Role, or SD. These hooks are not intended as escapes in which arbitrary information can be encoded when the formalism makes it hard to express a fact about the world, but rather as a means of direct advice to the interpreter with clear import. The code pointed to by an IHook must be constructed from interpreter primitives (e.g., functions like "CreateConcept", "SatisfyRole", etc.), and the IHook must specify the place in the interpreter from which the code is to be invoked.

IHooks have the following annotation structure:

<Basic-invocation-type Situation-description Keyword>.

The basic invocation type is either "PRE-", "POST-", or "WHEN-". Each interpreter function, before it executes its main body of code, evaluates as preconditions any applicable procedures whose IHooks start with "PRE-". If any procedure fails, the function returns immediately, and never alters any structure. Upon success of the pre-conditions, the function does what it is supposed to, and then evaluates the "POST-" conditions. Again, if any condition fails, the entire operation is undone, and the function aborts. Finally, if the post-conditions are met, "WHEN-" procedures are run to perform side-effects.

Applicability of attached procedures is determined by the current situation and keyword. Situation descriptions are simply "individuating", "modifying", "changing", etc. -- one corresponding to each operation that can be done on an epistemological primitive. These are organized into a simple hierarchy, so that certain sets of functions can trigger the same procedure. Keywords are user-specifiable and arbitrary. They allow a crude form of inheritance overriding for IHooks: a Concept, Role, or SD inherits the set of procedures from all of its parents. However, only one procedure with a given keyword -- the most specialized one -- is evaluated.

5.7 Implementation

The impression we have given that there is a single KLONE interpreter that deals with the epistemological primitives described here is a bit misleading. KLONE is implemented (in Interlisp) as a set of interpreter primitives. Together these form an "interpreter". However, these primitive functions for building, accessing, and removing structure are not organized into a single cohesive program. Instead, they may be used in combination by higher-level functions (matching, reasoning by analogy, deduction, etc.) to construct and maintain a KLONE data base. Each function guarantees structural integrity, and the set of functions together constitute the only necessary access to the KLONE structures. In this way, Concepts, Roles, and SD's are supported as abstract data types. The functional interface provides a clean, implementation-independent definition for the types of entities that KLONE supports.

The principal motivation for providing a set of primitive functional pieces out of which "higher-level" procedures can be built, and not a particular set of matching, deduction, etc.

procedures, is that we do not yet have a clear enough understanding of these issues to allow us to provide powerful procedures at this higher level. Experience with matchers in the field in general has been equivocal. We have chosen instead to provide a basic set of tools for building different variants on an experimental basis. Since there is no general understanding of things like matching and reasoning by analogy, it seems wise not to commit the basic package to some ad hoc set of processing routines.

The KLONE functions depend on the fact that the set of connections between Concepts, Roles, and SD's is fixed in advance. In order to implement, say, a function that finds a (possibly inherited) restriction for a Role, we need to be able to anticipate all possible forms of inheritance that will be encountered. The function can then look for immediately accessible values and, if none are found, can call a variant of itself recursively depending on the type of Role inheritance connector it encounters. A complete set of Role inheritance functions, including the provision for multiple super-concepts and multiple super-roles, has been implemented based on the small set of possible inter-Role relationships.

Since the users of KLONE "see" only abstract structures for Concepts, etc., it is not necessary for them to think of the network as a set of nodes interconnected by links. Instead they can view Concepts as sets of Roles and SD's. The functions deal only with those entities (and their "epistemological" relations), and never attempt to make or break simple local link-like connections. This is important considering that structured inheritance, by means of a Cable that contains many interdependent connections, is a centered feature of KLONE. Thus, Cables are KLONE's solution to one problem with the traditional semantic network metaphor in general: the apparent

independence of each link from all other links.

In addition to the manipulation primitives, we have provided a facility that reads and writes KLONE networks expressed in a simple notation. This aids interactive writing and debugging of KLONE applications by making it possible to refer to and view swatches of the network. Additionally, this facility can be used to read and write KLONE networks as symbolic files. A network printing and display program using an expanded "pretty-printed" notation is also provided. In order to better track the developing system with documentation, we have included a feature that automatically compiles labeled program comments into text descriptions of the KLONE functions, their arguments, prerequisites, side-effects and output. The result is a kind of reference manual for KLONE that can be produced in an updated version as frequently as desired.

6. PRESENTATION SYSTEM CONCEPTS

6.1 Presentation Model

Since AIPS per se includes neither a world model nor a user model, these things being application dependent, our discussion of AIPS concepts begins with the presentation model. Throughout this discussion we will continue with the convention of capitalizing the names of KLONE Generic Concepts and using mixed upper and lower case names for Roles. This has been done because in some cases the name of a Role is identical with the name of a generic concept used to describe the Role's potential fillers. The words "instance" and "individual" are used to denote KLONE Individual Concepts descendent from named Generic Concepts.

As mentioned above, while we ultimately expect the presentation model to be populated with descriptions of a number of generic presentation forms such as "map", "table" and "menu", the top level concept -- PRESENTATION -- is not yet specialized into such types (see Figure 7). This concept describes the linkage between domain objects and viewable objects. An individual of PRESENTATION represents the depiction of some real world thing (DomainObject) as some graphic entity (Style) located onto a viewable surface by some process (Injection.) The filler of the Style Role is obliged to be an instance of DISPLAYFORM, a drawable figure. The value restriction on the DomainObject Role describes the world of depictable objects.

INJECTION describes the locating process. It assumes that the domain object of the presentation is already located in some world coordinate system. That system is the filler of INJECTION's CoordinateSystem Role. The destination of the corresponding graphical entity is described by INJECTION's

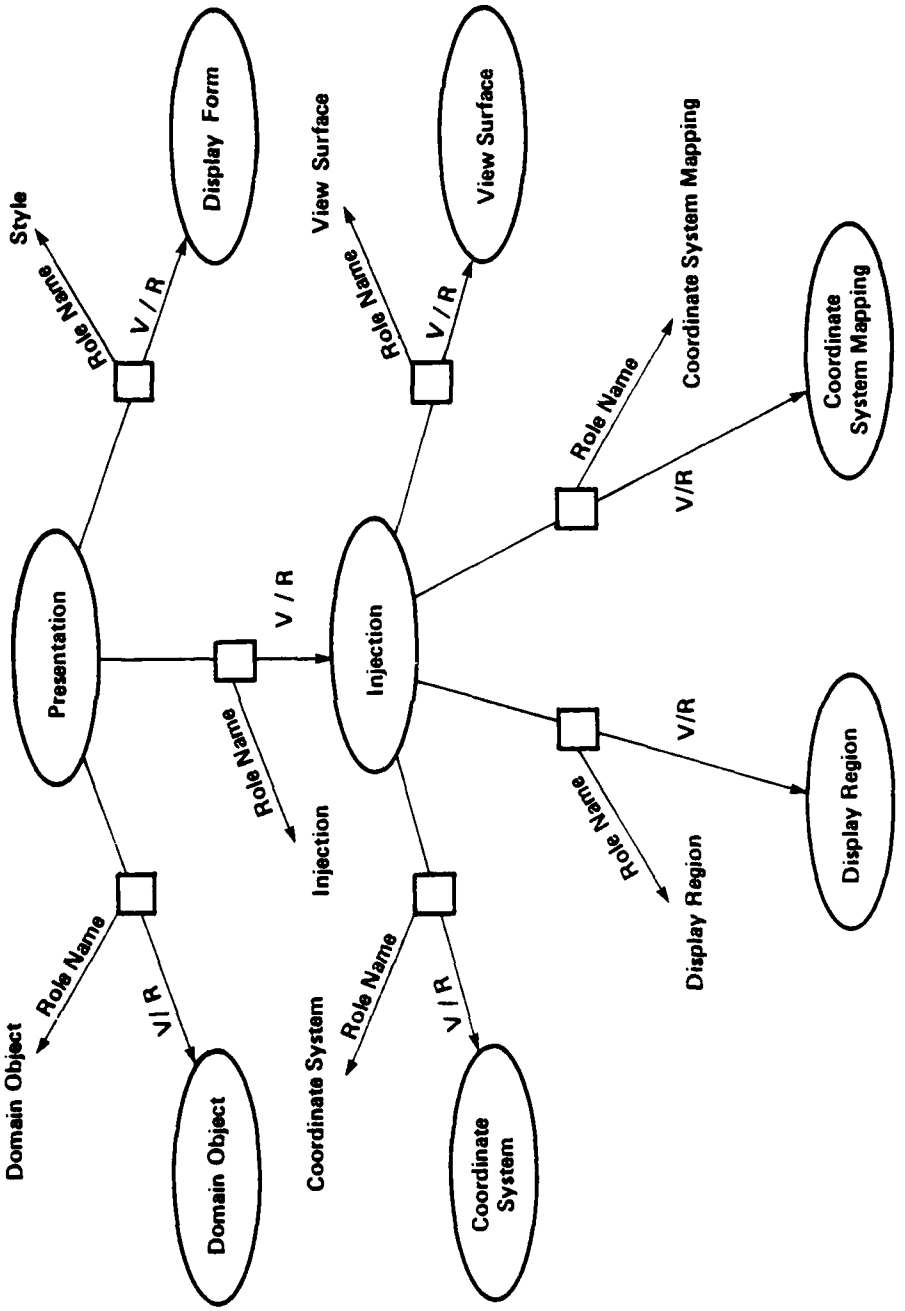

Presentation
V / R
Injection
Role Name
Injection
Style
Role Name
V / R
Display Form
View Surface
Role Name
V / R
View Surface
Role Name
Coordinate System Mapping
V/R
Coordinate System Mapping
Role Name
Display Region
V/R
Display Region
Domain Object
Role Name
V / R
Domain Object
Coordinate System
Role Name
V / R
Coordinate System

Figure 7.

ViewSurface and DisplayRegion roles. A VIEWSURFACE is a potentially viewable continuum with its own coordinate system. A DISPLAYREGION is a bounded area on that continuum. The filler of INJECTION's CoordinateSystemMapping Role describes a function for computing the depiction's location within the space described by these two roles.

Because the internal structure of INJECTION currently views the locating process as a transformation between coordinate systems, PRESENTATION is really a kind of map, somewhat generalized in that the nature of the mapping function is not restricted. This description is natural when depicting the locations of objects, but it becomes unwieldy when display location relates to something other than location in the domain world. For example, it is a bad way to describe scrolled text. For this reason, the current demonstration systems tend to operate in terms of lower level concepts and avoid describing many things as PRESENTATIONs. In particular, the display windows of the Middle Earth demonstration system are described in terms of DISPLAYREGION and TEXTDISPLAYREGION. Expanding PRESENTATION into a category of generic forms and generalizing the description of its Injection Role are among the most immediate research issues.

6.2 The Viewing Organization Model

As described above, the function of the viewing organization model is a semantics-insensitive formatting and layout process. VIEWSURFACE provides the medium for this process, a two-dimensional continuum. Since VIEWSURFACE has only one internal Role -- CoordinateSystem -- it is practically equivalent to the concept COORDINATESYSTEM that describes the potential fillers of that Role.

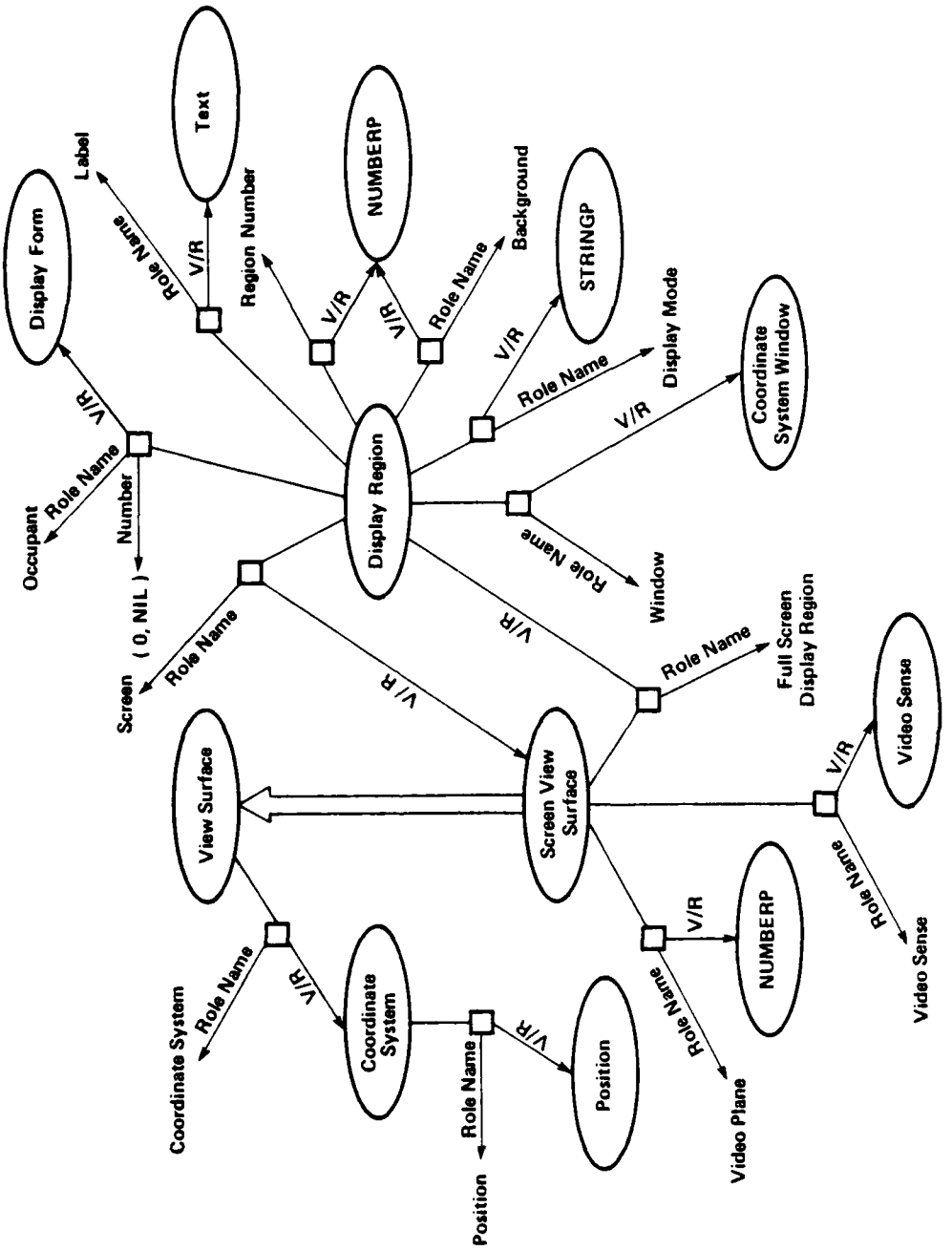

Display Region
Text
NUMBERP
STRINGP
Display Form
Label
Role Name
V/R
Region Number
Background
Display Mode
Coordinate System Window
Occupant
Number
(0, NIL)
Screen
Window
Full Screen Display Region
View Surface
Screen View Surface
Video Sense
Coordinate System
Position
Video Plane

Figure 8.

A VIEWSURFACE does not necessarily correspond to the display surface of an output device. Those that do are described by a more specialized concept: SCREENVIEWSURFACE. SCREENVIEWSURFACE inherits the CoordinateSystem Role of its super-concept and adds others that describe a device display surface: the VideoPlane, VideoSense and FullScreenDisplayRegion Roles. The filler of the VideoPlane Role is a number which identifies a plane of bit-map display memory. In a system with color capability, this might indicate one of the monochrome planes of a color display. In the BMG-11 bit-map display, this number designates either of two black and white displays. The VideoSense Role tells whether drawing is done with white on black or vice versa. Finally, the FullScreenDisplayRegion Role takes as its filler an instance of DISPLAYREGION which describes the size and shape of the display area.

An instance of DISPLAYREGION is a bounded area on some view surface, which need not necessarily be an instance of SCREENVIEWSURFACE. Those Roles of DISPLAYREGION that concern display regions on screen view surfaces are optional and need not be filled if the display region is over a non-screen view surface. The other two Roles are the Window and Occupant Roles. The filler of the Window Role must be an instance of COORDINATESYSTEMWINDOW, which describes a rectangular boundary by the positions of its upper right and lower left corners. The fillers of the Occupant Role are the instances of DISPLAYFORM that inhabit the display region. The remaining Roles of DISPLAYREGION all have to do with display regions on screen view surfaces. They describe DISPLAYREGION, in effect, as a primitive kind of display window. The filler of the Screen Role is the associated screen view surface. The RegionNumber Role gives the identifying number of the corresponding bit-map display region. The Background Role gives a 16-bit long pattern used for

background shading. The DisplayMode role gives the writing mode, which is one of ADD, REMOVE, FLIP, or OVERWRITE. Finally, the Label Role designates a piece of text which is displayed as a title.

TEXTDISPLAYREGION is a descendant of DISPLAYREGION used, as its name implies, for displaying text. This is a separate concept for a pragmatic reason. The automatic scrolling of text through a display region is a function of the BMG-11 graphics processor program. In order to keep the region's label from scrolling along with the other contents, it is necessary to use two bit-map display regions, one inside of the other. The innermost one contains the text and does the scrolling. The outer one, only slightly larger, contains the label. TEXTDISPLAYREGION thus adds an InnerRegionNumber Role to the above Roles inherited from DISPLAYREGION.

Display regions not on screen view surfaces provide a context for operating on graphic entities before they are displayed. Injections from several presentations can play onto a single non-screen view surface. The subsequent transformation to a screen view surface can be used to effect the final scaling and clipping. This transformation from one view surface to another is described by PROJECTION. PROJECTION has just three roles: FromSurface, ToSurface and CoordinateSystemMapping. The FromSurface Role is analogous to the CoordinateSystem Role of INJECTION, except that it designates a view surface rather than the domain world as the source of location information. The CoordinateSystemMapping Role is the same as in INJECTION. Unlike INJECTION however, there is no DisplayRegion Role to describe a window on the destination surface. Instead, any clipping is specified by the FromWindow and ToWindow Roles of COORDINATESYSTEMTRANSFORMATION.

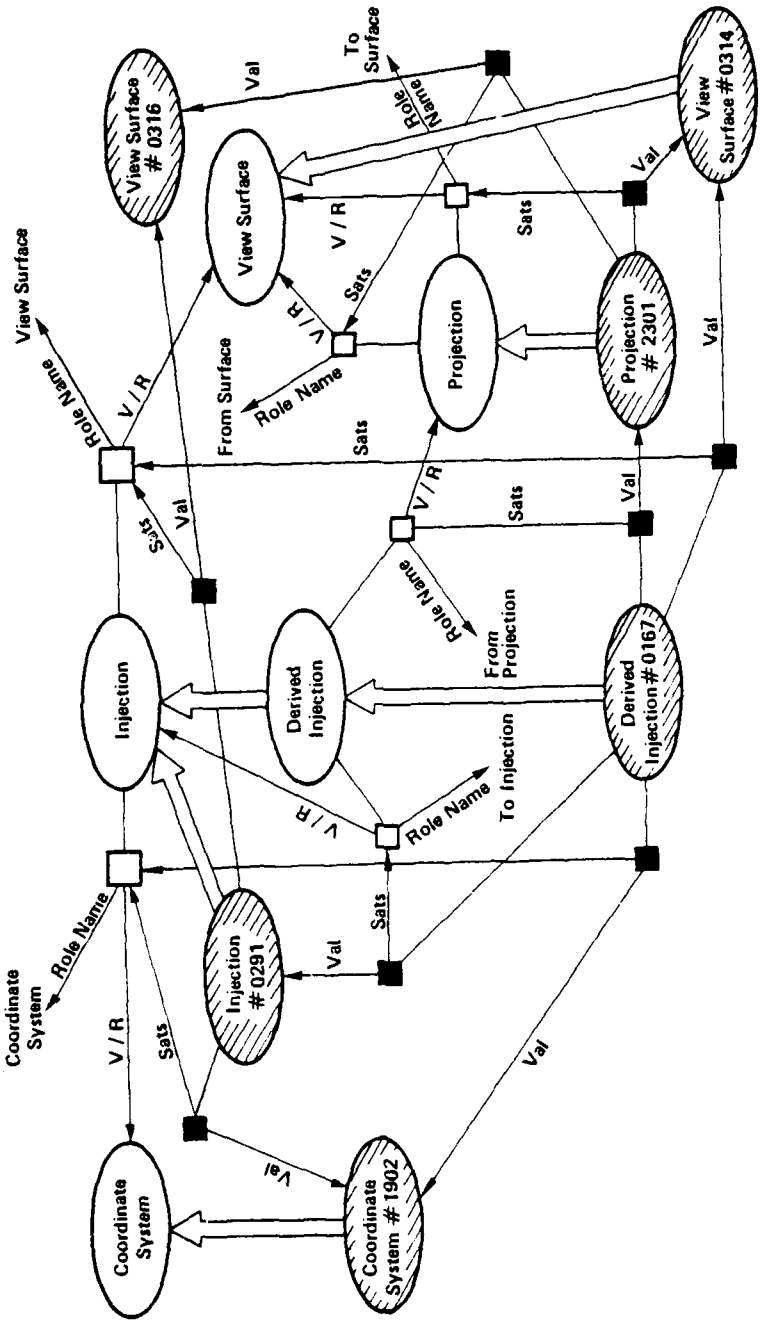

View Surface #0316
Val
To Surface
Role Name
View Surface #0314
View Surface
V / R
Sats
Val
View Surface
Role Name
V / R
Sats
Projection
Projection #2301
Val
From Surface
Role Name
Sats
Sats
Val
V / R
Sats
Val
Role Name
From Projection
Injection
Derived Injection
Derived Injection #0167
To Injection
V / R
Role Name
Coordinate System
Role Name
Injection #0291
Val
Sats
V / R
Sats
Val
Val
Coordinate System
Coordinate System #1902

Figure 9A.

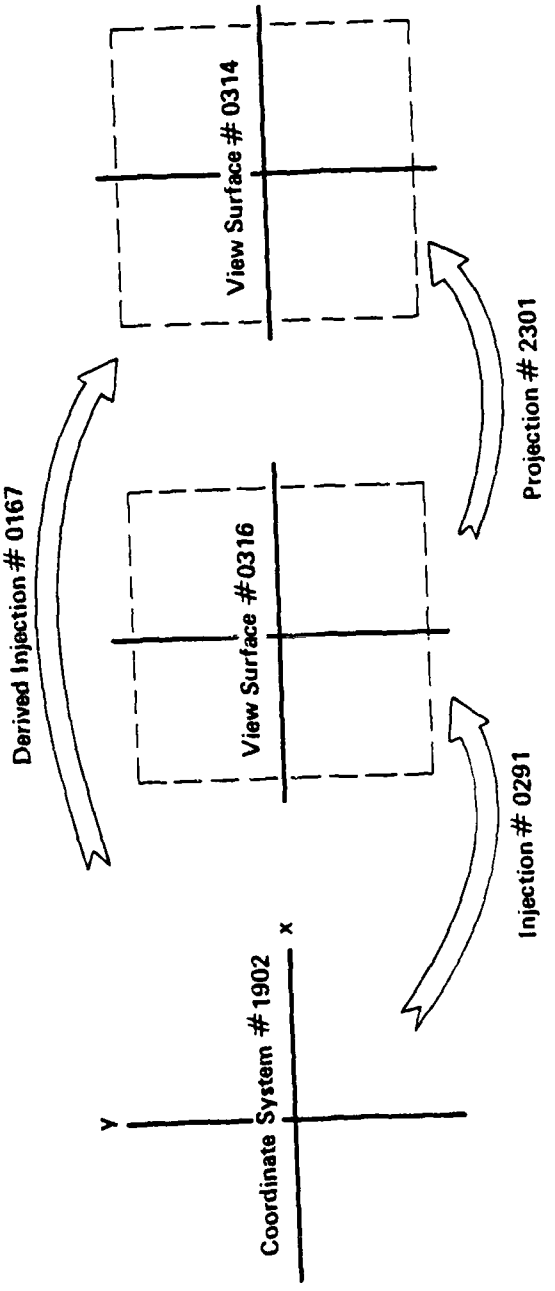

View Surface # 0314
Projection # 2301
View Surface # 0316
Derived Injection # 0167
Injection # 0291
Coordinate System # 1902
x
y

Figure 9B.

Since a presentation may involve cascading across several intermediate view surfaces, it would be necessary to characterize the positions of the injected display forms in each of these unless there were some means of combining the transformations. This is the function of the DERIVEDINJECTION concept. An instance of DERIVEDINJECTION represents a single mapping that combines some projection with some injection (or, recursively, some other derived injection), eliminating the intervening view surface. Since DERIVEDINJECTION is a descendant of INJECTION, it inherits INJECTION's CoordinateSystem, ViewSurface, DisplayRegion and CoordinateSystemMapping Roles. To these it adds two Roles called FromProjection and FromInjection, whose fillers are the projection and injection being spanned. Since in AIPS any position referred to within some coordinate system is dignified with an Individual Concept, DERIVEDINJECTION enables a considerable economy not only in transformational arithmetic, but also in the size of the display description.

The property of position on a view surface is always described in terms of some instance of COORDINATESYSTEM. In fact, AIPS defines three different taxonomic categories: COORDINATESYSTEM, 2DIMENSIONALCOORDINATESYSTEM, and CARTESIANCOORDINATESYSTEM. COORDINATESYSTEM and its descendants have just one Role called Position, which can have any number of fillers. These are the discrete locations in the coordinate system that are referenced elsewhere in the description network. Since there are no other Roles, the coordinate system is really described implicitly, in terms of transformations linking it to other systems. At the moment, instances of the three different coordinate system types can be interchanged freely with no effect so far as AIPS is concerned. In the future, structural descriptions on these concepts will detail their distinguishing restrictions.

Instances of the concept COORDINATESYSTEMMAPPING describe the transformations linking coordinate systems. COORDINATESYSTEMMAPPING has four Roles: FromWindow, ToWindow, CoordinateTransformationFn and InverseMapping. The FromWindow and ToWindow Roles are filled by instances of COORDINATESYSTEMWINDOW, which describe the locations of rectangular clipping windows on the source and destination coordinate systems. The filler of the CoordinateTransformationFn Role is an instance of COORDINATETRANSFORMATIONFN, whose two roles give the transformed positions of the zero vector and unit vector in the destination system. The filler of the InverseMapping Role, which is optional, is the inverse of the filler of the CoordinateTransformationFn Role. These descriptions of coordinate mappings are currently limited to rectilinear transformations on cartesian coordinate systems. In the future we hope to generalize this characterization.

In parallel with the three taxonomic categories for coordinate systems, there are three categories for locations or positions: POSITION, 2DIMENSIONALPOSITION, and CARTESIAN POSITION POSITION has just one Role named Coordinates. This can be filled with an arbitrarily long position tuple. 2DIMENSIONALPOSITION has two roles, named X and Y, which differentiate the Coordinate Role of POSITION. CARTESIANPOSITION has two roles called Abcissa and Ordinate which modify the X and Y roles of 2DIMENSIONALPOSITION. Any description in the network concerning location must refer to some instance of one of these three generic concepts. This restriction is somewhat circumvented by the generic concept POINTSLISTDISPLAYFORM, which allows an arbitrary sequence of line segments to be embedded in the description of a single display form as a list of LISP tuples rather than as a list of instances of POSITION. As a filler of the Occupant Role of some instance of DISPLAYREGION, however, an

instance of POINTSLISTDISPLAYFORM has a discrete location. By virtue of being "injected" onto a view surface, it is linked to some instance of one of the three position concepts.

6.3 Realization Model

DISPLAYFORM is the central concept of the Realization Model. All of the concepts that we will discuss at this level of knowledge are descendants of DISPLAYFORM. All of them describe things that can be drawn at specified locations. The meat of these descriptions are attached procedures for drawing the different forms, rather than their internal Role structures. Indeed, DISPLAYFORM has just one role: ComputedCenter, which is the idealized location of the form. This role is filled only when it becomes necessary to describe the display form as having some single location, typically when trying to decide whether the user has designated it with the graphic tablet. The description of the form's location used for drawing purposes is instead contained in Roles of the generic concepts specializing DISPLAYFORM. POINT, for example, has a Role called Position, and LINE a Role called EndPoint.

Taxonomically, DISPLAYFORM divides into two subordinate concepts: DISPLAYFORMPRIMITIVE and DISPLAYFORMCOMPOSITE. As the names imply, the former are atomic graphic entities while the latter are composed out of more primitive forms. An important aspect of this distinction is that it tells where the procedural knowledge for drawing the display form is to be found. If the form is primitive, the drawing procedure will be found directly attached to the generic description. If not, it is arrived at by a more elaborate process of invoking (and possibly negotiating among) the drawing procedures of constituent forms. DISPLAYFORMPRIMITIVE is purely a taxonomic entity; it adds no new

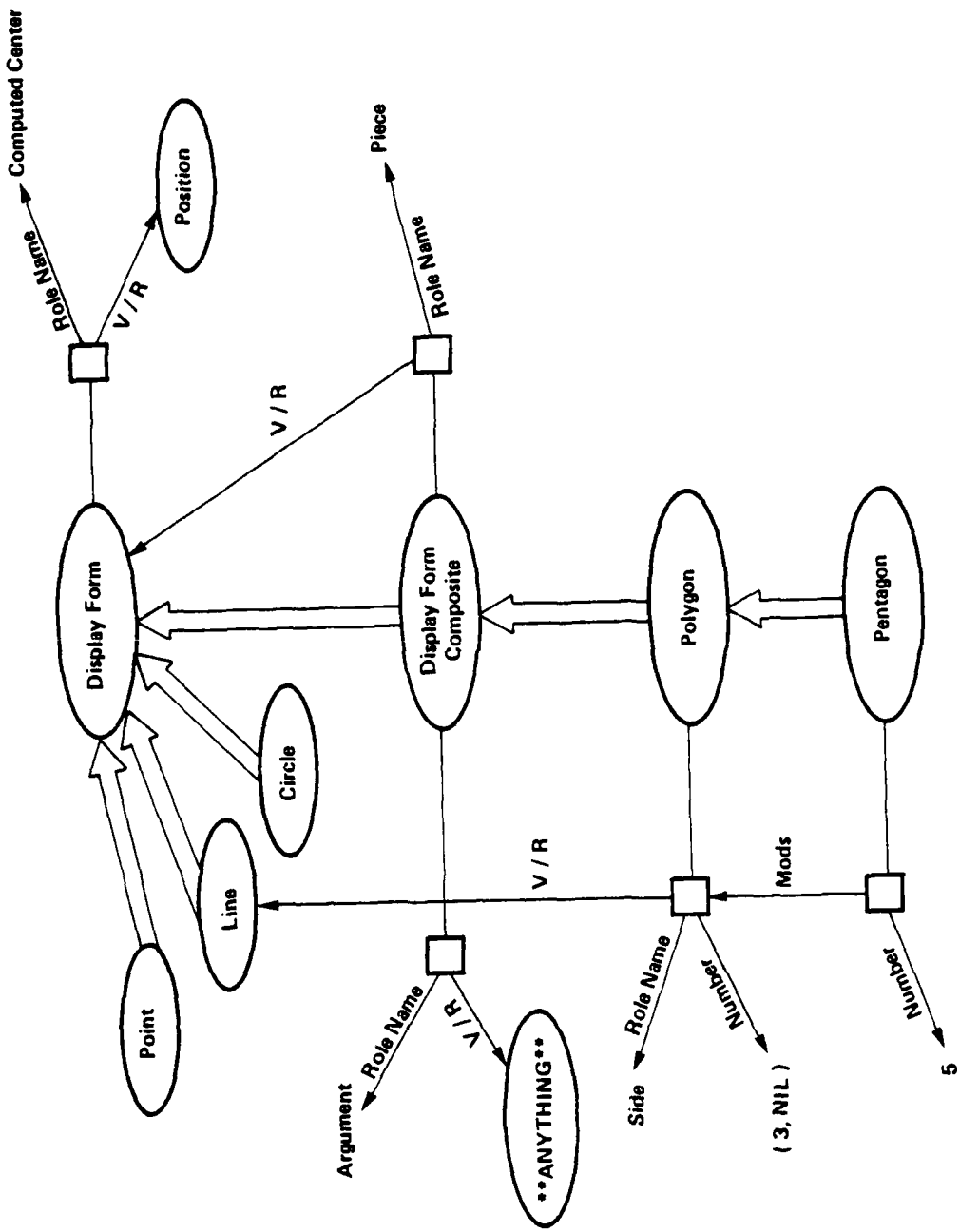

Computed Center
Role Name
V/R
Position
Piece
Role Name
V/R
Display Form
Display Form Composite
Polygon
Pentagon
Circle
Line
Point
V/R
Mods
Argument
Role Name
V/R
ANYTHING
Side
Role Name
Number
(3, NIL)
Number
5

Figure 10.

Roles to those of DISPLAYFORM. DISPLAYFORMCOMPOSITE adds two Roles called Piece and Argument. The fillers of the Piece Role are the constituent forms of the composite. For example, an instance of TRIANGLE would have three fillers for this role, each an instance of LINE. The Argument Role is differentiated by DISPLAYFORMCOMPOSITE's descendants into Roles that describe such things as size, shape and location. REGULARPOLYGON, for example, is a descendant of DISPLAYFORMCOMPOSITE whose Center, NumberOfSides and LengthOfSide Roles differentiate the Argument Role.

The principal primitive display forms are POINT, LINE, CIRCLE, TEXT, and CONNECTINGLINE. POINT, as mentioned above, adds a single Role called Position, while LINE adds a Role called EndPoint, which is expected to have two fillers. CONNECTINGLINE has a Role structure similar to that of LINE, but the endpoints of the line are also specified in terms of the display forms which the line connects. CONNECTINGLINE includes attached procedures for finding end points based on the locations of these forms, such that the connected forms are not over-printed by the line. CIRCLE uses the Roles Center and Radius to describe location and size. TEXT includes three Roles: Position, String and Font. The Position Role describes the position of the lower left hand corner of the text fragment, the String Role is filled with the appropriate Interlisp string, and the Font Role is filled with a number that designates the character font to be used for printing.

For the most part, the set of composite display forms is application dependent. For example, in an AIPS system for naval tactical displays, this category would include the standard NTDS symbology. The composite display forms that are already defined in AIPS are the simple geometric shapes. The head of this sub-lattice is the concept POLYGON. It modifies the Piece Role

inherited from DISPLAYFORMCOMPOSITE into a single Role called Side, whose fillers in an individual polygon are the lines making up the sides. Under POLYGON there are two major subdivisions: the regular and irregular polyhedra. One chain descends through REGULARPOLYGON, REGULARTRIANGLE, SQUARE, REGULARPENTAGON, etc. The other chain extends through TRIANGLE, RHOMBUS, PARALLELOGRAM, RECTANGLE, TRAPEZOID, PENTAGON, and so forth. These two groups are separated because they require different characteristics for instantiation and drawing. Regular polyhedra are completely specified by the number of sides and the length of an edge, while arbitrary triangles, for example, require some combination of angles and edge lengths.

6.4 Procedural Knowledge

At the current time, the procedural knowledge attached to the AIPS SI-Net divides roughly into two bodies according to function. One set of attachments is concerned with finding appropriate fillers for Roles in new Individual Concepts or adjusting Role fillers in existing ones. For example, when a new instance of CONNECTINGLINE is made and described as connecting two specified forms, attached procedures are used to determine the actual position of the line's end points. Such procedures may have wide-ranging side effects, e.g., a display form is actually drawn as a side effect of its filling the Occupant Role of a display region. This kind of procedural knowledge is found in the presentation and viewing organization models. It is attached using the IHook feature of KLONE, so that the procedures are automatically entered under specified permutations of the SI-Net. The other type of procedural knowledge, which is found at the Realization Level, concerns how to manipulate display forms. These procedures are attached as inherited data under various keynames such as HowToDraw, HowToErase and

HowToFindCenter.

The procedurally expressed knowledge in the presentation model consists of two IHook procedures. The first, called DeriveElaboration, is called whenever an instance of PRESENTATION is created. It checks to see whether the presentation has a filler for its Injection Role and whether that injection is onto a screen view surface. If these conditions are met, DeriveElaboration adds the filler of the presentations's Style Role to the fillers of the appropriate display region's Occupant Role, which ultimately causes the display form to be drawn. The other procedure, AfterIndividuateInjection, is called whenever an instance of INJECTION is created. Its main function is to create an individual of DERIVEDINJECTION whenever the injection is onto a non-screen view surface from which there already leads some projection. This process then recurses due to the newly created injection, thus cascading derived injections until a screen view surface is reached. AfterIndividuateInjection also causes an instance of DISPLAYREGION to be created if the injection is onto a screen view surface and there is currently no filler for its DisplayRegion Role.

Most of the viewing organization model concepts discussed above have IHook procedures that fire whenever individuals of these concepts are created. For example, PROJECTION has an IHook called DeriveInjectionAfterIndividuateProjection, whose function is to set up an instance of DERIVEDINJECTION as discussed above. The function DeriveDerivedInjectionRoles then fires from a "PRE-KLDeriveRoles" IHook in order to fill its Roles. DISPLAYREGION and TEXTDISPLAYREGION each have their own "WHEN-KLIndividuate" IHooks which cause appropriately sized and located bit-map terminal display regions to be allocated and drawn on the display. COORDINATESYSTEMMAPPING has an elaborate "WHEN-KLIndividuate" IHook that can derive the remaining role

filler from any two of the FromWindow, ToWindow or CoordinateTransformation Roles that are specified, and then goes on to derive the filler of the InverseMapping Role.

In the realization model there are four groups of procedures attached as inherited data under four different key names: HowTo Draw, HowToErase, HowToFindCenter and HTCDistanceSquaredFromDF. HowToDraw, HowToErase and HowToFindCenter procedures are attached to each of the primitive display forms POINT, LINE, CIRCLE, TEXT, REGULARPOLYGON and DISPLAYFORMCOMPOSITE. In addition, DISPLAYFORMCOMPOSITE has a procedure attached under the HTCDistanceSquaredFromDF key name which can be used to compute euclidean distances in order to determine what display form is closest to a location input from the graphic tablet.

6.5 An Example Presentation

As an example of a presentation description and its expansion into a display, consider the problem of realizing a simple map of a task force formation. We will first develop a description of such a map, and then show how individuating the description can cause the map to be displayed. The description will provide for automatic scaling of the map, a polar coordinate reference grid, and appropriate Naval Tactical Display System (NTDS) symbols for each element of the formation.

To keep our example simple, we will represent a formation as a Generic Concept with only two Roles: Flagship and Track. The fillers of these roles describe the task force elements as entities with a world location in latitude and longitude and a track type, which indicates whether the track is on the surface, subsurface, or in the air. In Figure 11, an abbreviation has been used for FORMATION's Structural Description S1, which

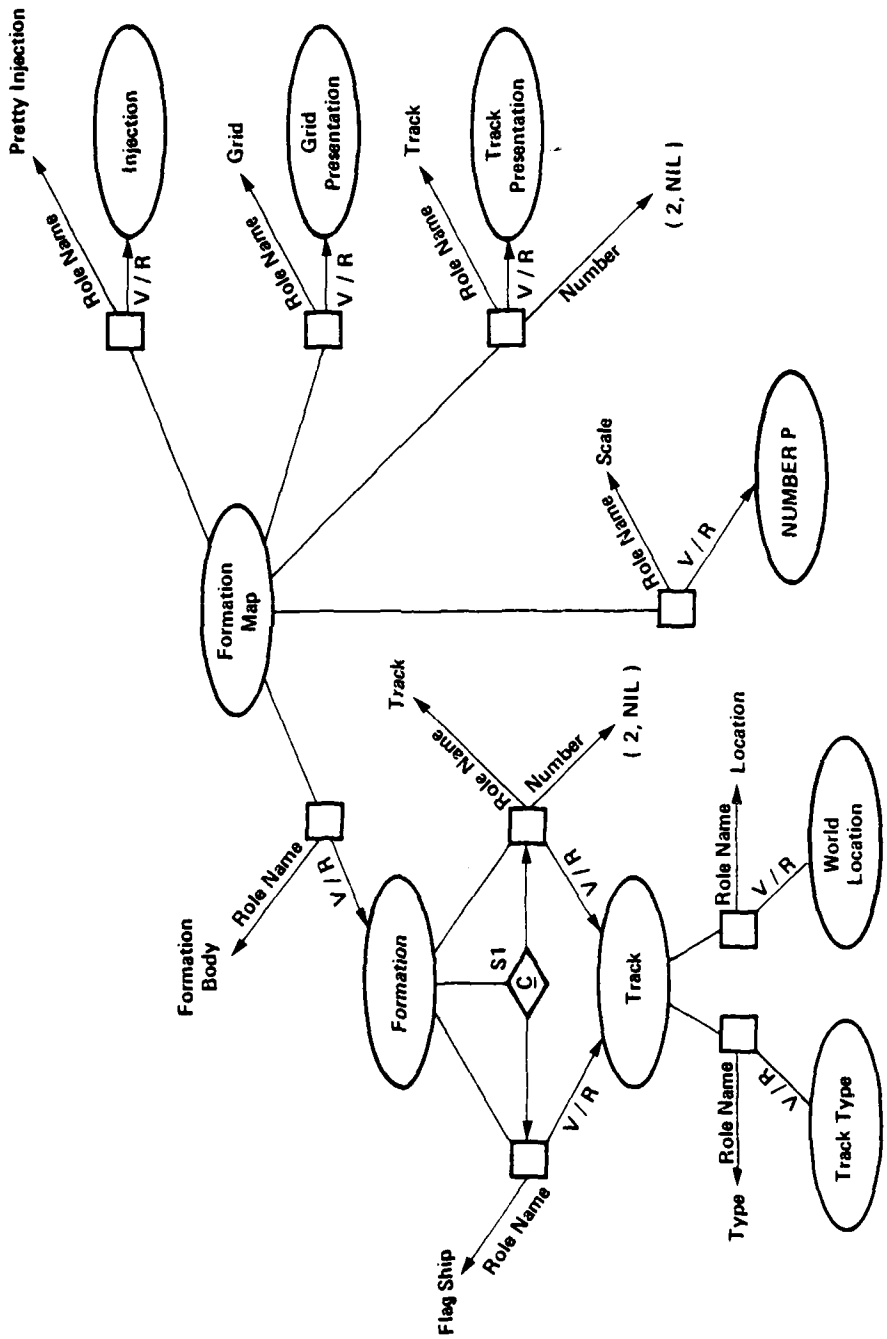

Pretty Injection
Injection
Role Name
V / R
Grid
Grid Presentation
Role Name
V / R
Track
Track Presentation
Role Name
V / R
Number
(2, NIL)
Formation Map
Role Name
Scale
V / R
NUMBER P
Track
Role Name
Number
(2, NIL)
Formation Body
Role Name
V / R
Formation
S1
C
V / R
Track
Role Name
Location
V / R
World Location
Role Name
V / R
Track Type
Type
Flag Ship
Role Name
V / R

Figure 11.

describes the constraint that the filler of the Flagship Role must be among the fillers of the Track Role.

The description of our simple map, FORMATIONMAP, includes four Roles: Injection, GridPresentation, TrackPresentation, and Scale. The filler of the Injection Role will be an instance of INJECTION which, for the sake of simplicity, is onto a pre-specified view surface within a pre-specified display region. The coordinate system mapping of this injection will be determined during the process of individuating FORMATIONMAP. The Scale Role will be filled with a number representing the number of nautical miles per division of the reference grid. The GridPresentation Role will be filled with an instance of PRESENTATION for the reference grid of the map, and the TrackPresentation Role by the presentations of the tracks that are the individual task force elements. The procedural knowledge attached to FORMATIONMAP includes procedures for filling all four Roles.

Figure 12 details the description of a track presentation. We see that TRACKPRESENTATION is described chiefly by virtue of being a descendant of PRESENTATION: a track presentation is a presentation with certain details specified. In fact, each of the Roles of PRESENTATION is modified in some way by TRACKPRESENTATION. The Style Role of PRESENTATION is Modified to be more restrictive: instead of any display form, the filler of TRACKPRESENTATION's inherited Style Role must be an instance of NTDSSYMBOL. Similarly, the DomainObject Role of PRESENTATION is Modified to require that its filler be an instance of TRACK. Finally, two Structural Descriptions of FORMATIONMAP, S2 and S3, require respectively that the filler of TRACKPRESENTATION's Injection Role be the same as the filler of the containing FORMATIONMAP's PrettyInjection Role, and that the filler of TRACKPRESENTATION's DomainObject Role be one of the fillers of

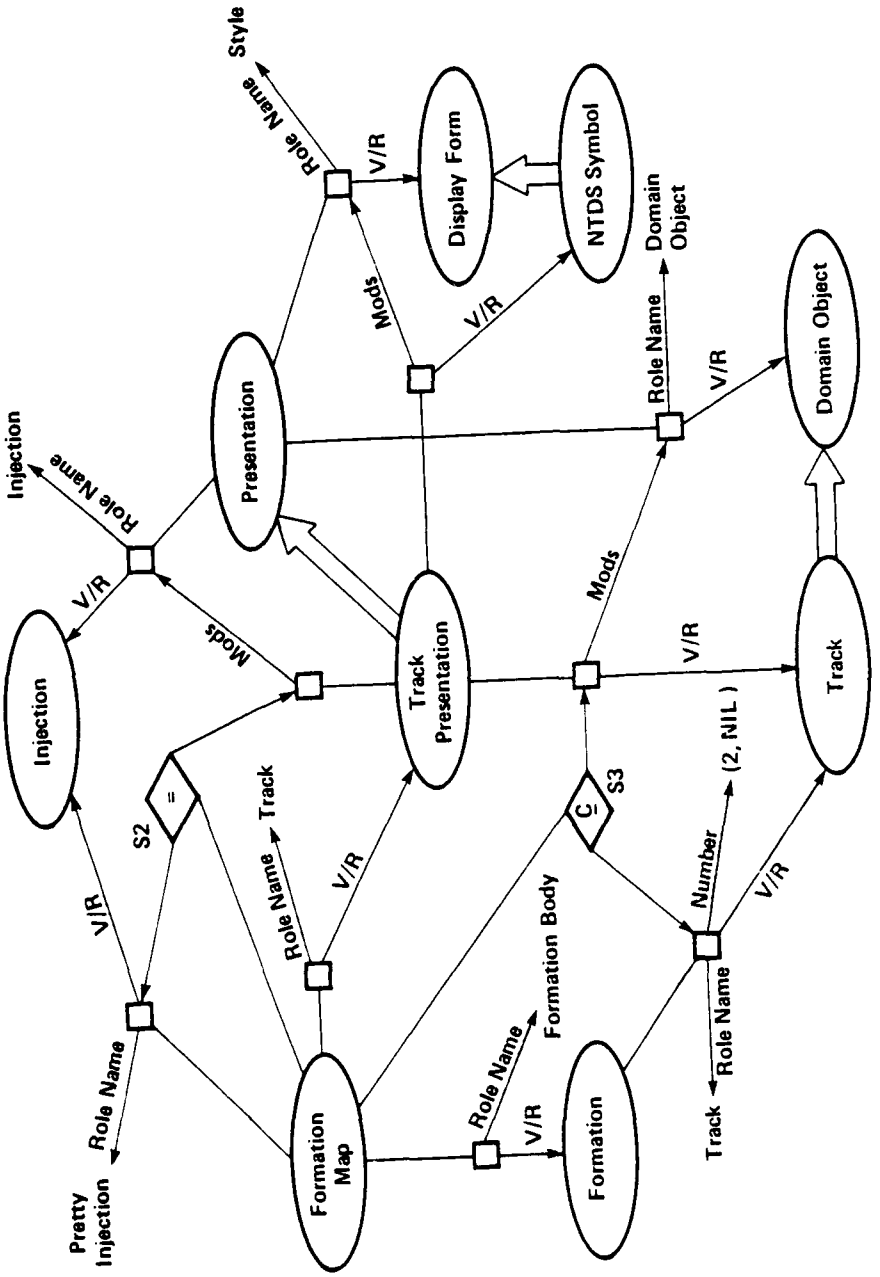

Style
Role Name
V/R
Display Form
NTDS Symbol
Domain Object
Mods
V/R
Role Name
V/R
Domain Object
Presentation
Injection
Role Name
V/R
Mods
Track Presentation
Mods
V/R
Track
Injection
S2
=
Track
Role Name
V/R
V/R
S3
(2, NIL)
Number
V/R
Formation Body
Role Name
Role Name
Pretty Injection
Formation Map
Role Name
V/R
Formation
Track
Role Name

Figure 12.

the associated formation's Track Role. A "WHEN-KLIndividuate" IHook attacked to TRACKPRESENTATION is responsible for the Style Role with an appropriate instance of of NTDSSYMBOL.

Figure 13 shows that the description of GRIDPRESENTATION is similar to that of TRACKPRESENTATION: it is a kind of presentation with certain details fixed. The DisplayForm Role is constrained to be filled by an instance of POLARGRID, a descendant of DISPLAYFORM. The DomainObject Role is Modified to require its filler to be an instance of GRIDLOCUS, a sort of place holder in the domain world that allows the center of the reference grid to be specified in world coordinates. The constraint that the origin of the reference grid be at the location of the task force flagship is described by Structural Description S4, which forces equivalence between the WorldLocation Role of the formation's flagship and the world location of the grid.

Finally, in Figure 14 we see POLARGRID and NTDSSYMBOL described as descendants of DISPLAYFORMCOMPOSITE. Two "arguments" are specified whenever an instance of POLARGRID is created: a number stating the scale of the reference grid (taken from the filler of the formation map's Scale Role) and the display region which is to contain the grid (taken from the DisplayRegion Role of the filler of the formation map's PrettyInjection Role). The grid itself is composed of four concentric range circles, eight radial lines, and a title. The relative positions of these elements are constants such that the grid just fits into a unit circle.

NTDSSYMBOL is described as a composite of two pieces of text: the TrackName and TrackSymbol Roles. The filler of the TrackSymbol role is an instance of TEXT because our plan is to use a single character from a special font set as the track

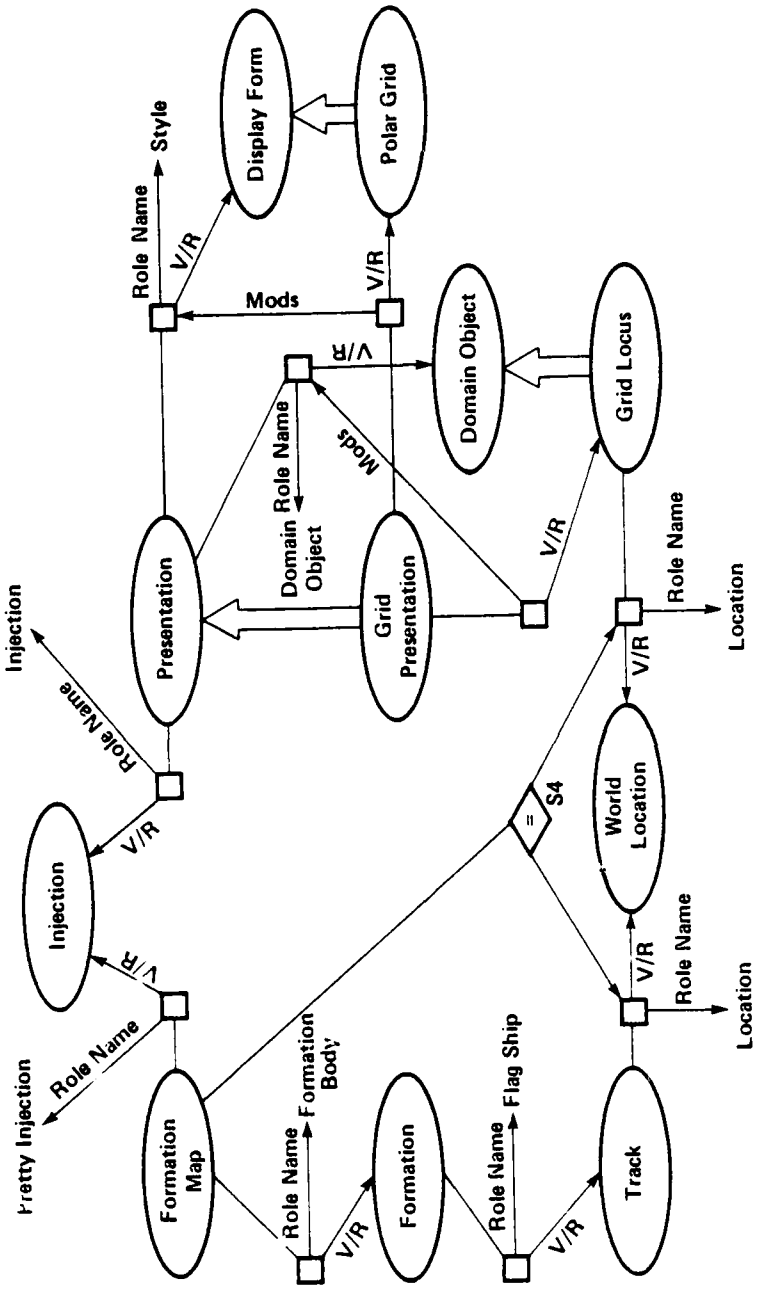
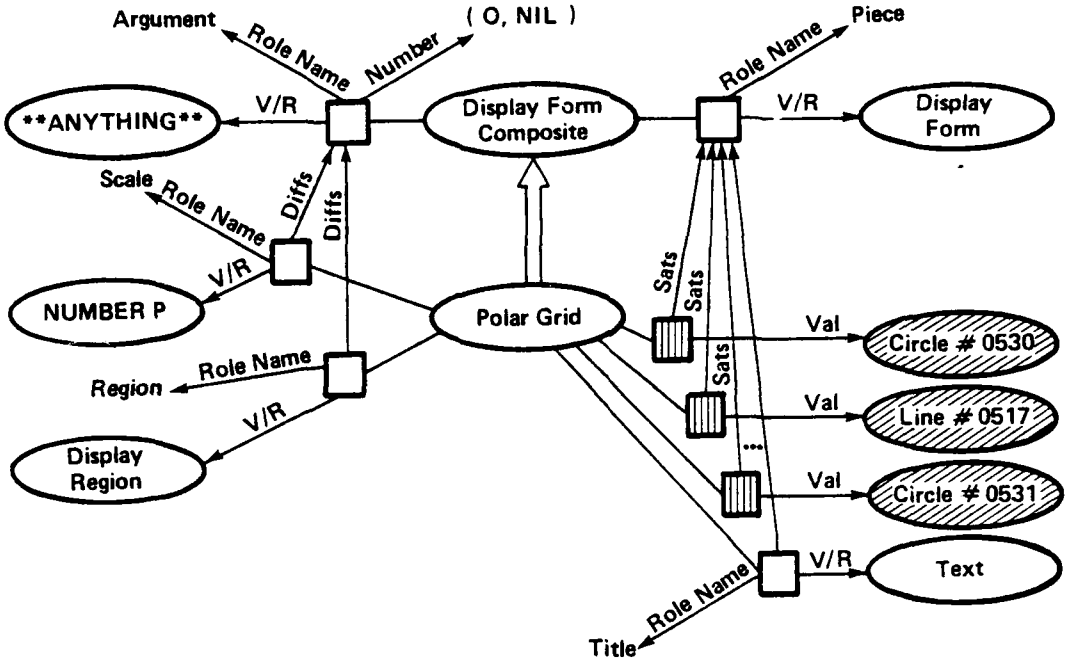

Display Form
Polar Grid
Style
Role Name
V/R
Mods
V/R
Domain Object
Grid Locus
V/R
Mods
Domain Role Name
Domain Object
Presentation
Grid Presentation
V/R
Role Name
Location
V/R
Injection
Role Name
V/R
Injection
S4
World Location
V/R
Role Name
Location
V/R
Pretty Injection
Role Name
Formation Map
Role Name
Formation Body
V/R
Formation
Role Name
Flag Ship
V/R
Track

Figure 13.


Argument
Role Name
Number
(O, NIL)
ANYTHING
V/R
Display Form Composite
Role Name
Piece
V/R
Display Form
Scale
Role Name
Diffs
Diffs
V/R
NUMBER P
Polar Grid
Sats
Sats
Sats
Val
Circle # 0530
Region
Role Name
Val
Line # 0517
V/R
Display Region
Val
Circle # 0531
V/R
Text
Role Name
Title

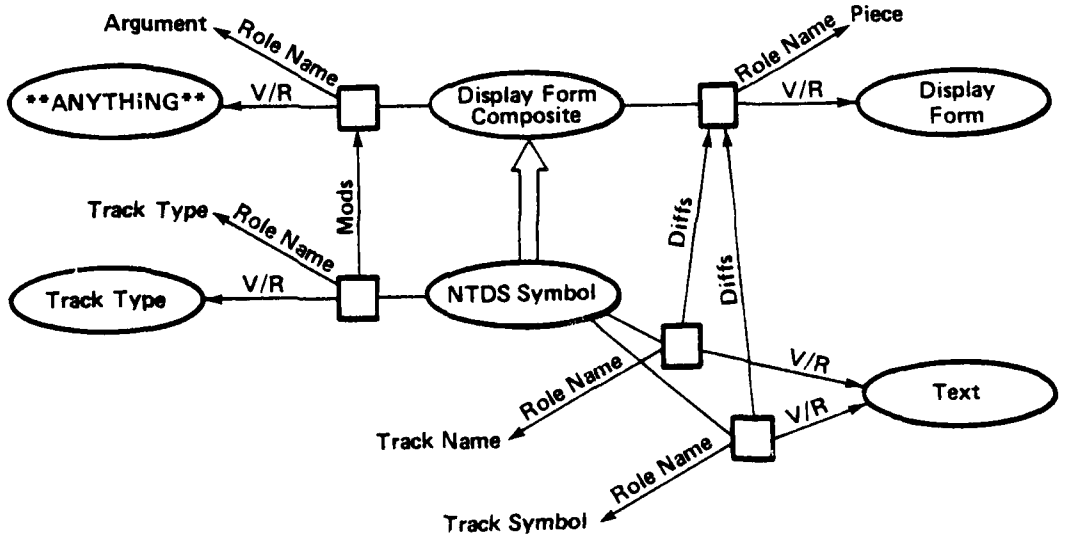

Argument
Role Name
ANYTHiNG
V/R
Display Form Composite
Role Name
Piece
V/R
Display Form
Track Type
Role Name
Mods
Diffs
Diffs
Track Type
V/R
NTDS Symbol
V/R
Text
Role Name
Track Name
V/R
Role Name
Track Symbol

Figure 14.

symbol. Instead of the standard alphanumeric characters, this font set will link each character code to an icon, a small picture contained in a single character cell.

To see how these descriptions function to create a display, consider the situation shown in Figure 15, wherein we already have an instance of FORMATION (in this case, FORMATION#0151) with filled in Roles. This is the group of tracks to be included in the final map. The user (either directly or indirectly, through some program) begins the map drawing process by causing an individual of FORMATIONMAP (FORMATIONMAP#0213) to be created whose FormationBody Role is filled by FORMATION#0151.

The "WHEN-KLIndividuate" IHook attached to FORMATIONMAP fills the new individual's PrettyInjection Role with an instance of INJECTION whose ViewSurface, CoordinateSystem and DisplayRegion roles are (for the simplicity of this example) program constants of the IHook. It then maps over the fillers of the Track Role in FORMATION#0151, examining their Location Roles, to determine an appropriate scale for the map. This is used to compute the CoordinateSystemMapping Role of the injection, and is saved for later use at FORMATION#0151's Scale Role. FORMATIONMAP's individuation IHook then begins the process of mapping over the fillers of FORMATION#0151's Track Role, adding fillers to FORMATIONMAP#0213's TrackPresentation Role, and then finishes by filling the GridPresentation Role.

As each filler of FORMATIONMAP#0213's TrackPresentation Role is individuated, the "WHEN-KLIndividuate" IHook on TRACKPRESENTATION fires which fills in the Style Role with an instance of NTDSSYMBOL according to the name and type of the track. Following this, the "WHEN-KLIndividuate" IHook on PRESENTATION causes the new instance of TRACKPRESENTATION to become a filler of the display region's Occupant Role. Finally,

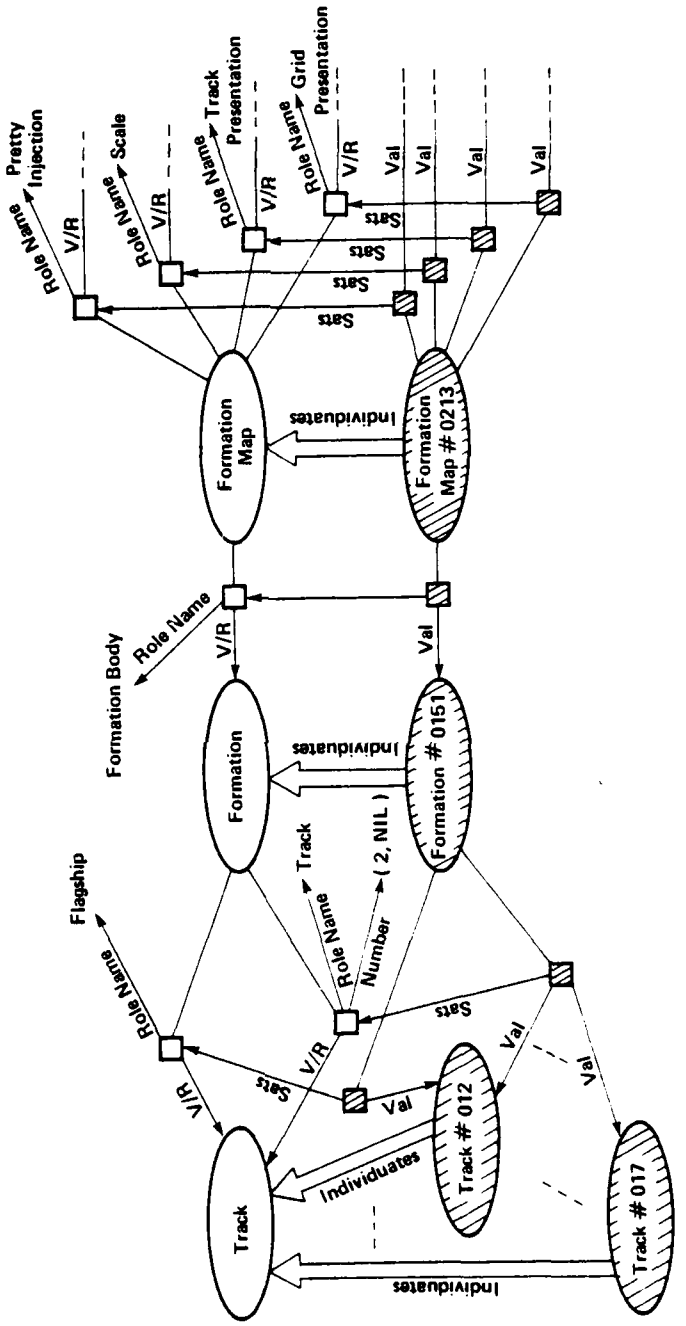

Pretty Injection
Role Name
V/R
Scale
Track Presentation
Grid Presentation
Val
Sats
Formation Map
Individuates
Formation Map # 0213
Formation Body
Formation
Formation # 0151
Track
(2, NIL)
Number
Flagship
Track # 012
Track # 017

Figure 15.

the "WHEN-KLSatisfyRole" IHook on Occupant causes the new occupant to be drawn by finding the appropriate "HowToDraw" information attached to the Generic Concept TEXT.

When all of the fillers of FORMATIONMAP#0213's TrackPresentation Role have been determined, the individuation IHook on FORMATIONMAP goes on to fill the GridPresentation Role with a new instance of GRIDPRESENTATION. This causes another "WHEN-KLIndividuate" IHook to fire, for the purpose of filling the new Individual Concept's DomainObject, Style and Injection Roles. An instance of GRIDLOCUS is created to fill the DomainObject Role. The "WHEN-KLIndividuate" IHook on GRIDPRESENTATION finds the filler for the grid locus' Location Role by looking at the Location Role of FORMATION#0151's Flagship Role filler. Next, the new presentation's Style Role is filled with an instance of POLARGRID with appropriately filled Scale and Region Roles. Finally, GRIDPRESENTATION's "WHEN-KLIndividuate" IHook causes the Injection Role to be filled with a copy of FORMATIONMAP#0213's PrettyInjection Role filler whose coordinate transformation function is derived so as to just map a grid of unit circle size and flagship track location onto the destination display region. With the role filling process at GRIDPRESENTATION complete, the "WHEN-KLIndividuate" IHook on PRESENTATION fires to add mapped versions of POLARGRID's Piece Role fillers to the Occupant Role of the destination display region, thus indirectly causing them to be drawn.

One thing to note in this example is that it actually requires very little procedural knowledge to be added to the pre-existing AIPS network. Most of what is needed is already there. The only substantial additions involved are a procedure for computing an appropriate scale for the map based on the spread in the world locations of the tracks, and a procedure for deriving the appropriate coordinate transform for the reference

grid according to the size of the destination display region.

Furthermore, significant changes can be made to the display via only minor and isolated modifications to the underlying description. The contents of the map, for example, can be easily changed by modifying the Roles of the Generic Concept FORMATION, or by adding Roles to the Concepts TRACK and TRACKPRESENTATION. It is also an easy task to change the type of reference grid used in the map by defining a new display form to take the place of POLARGRID. Thus, even at this rudimentary state of development, the use of declarative representation and procedural attachment has already made a substantial contribution to the flexibility of the display management system. The IHook triggering mechanism does add an extra level of indirection to the task of following the flow of control, but this is more than offset by the factorization of the system's knowledge enforced by the use of a taxonomic conceptual network.

7. THE MIDDLE EARTH DEMONSTRATION SYSTEM

In this section, we will give a brief description of one of the demonstration systems, called Middle Earth, that we have implemented using AIPS. The context for this system is an Over the Horizon (OTH) targeting task in which tracks of enemy and friendly ships are entered onto a map, projected forward in time, moved as necessary, and assigned as the targets and launch vehicles for Tomahawk missiles. In fact, this demonstration system contains no knowledge about the OTH targeting problem. Instead, it is a kind of computer-assisted sketch pad for drawing a certain sort of target assignment diagram.

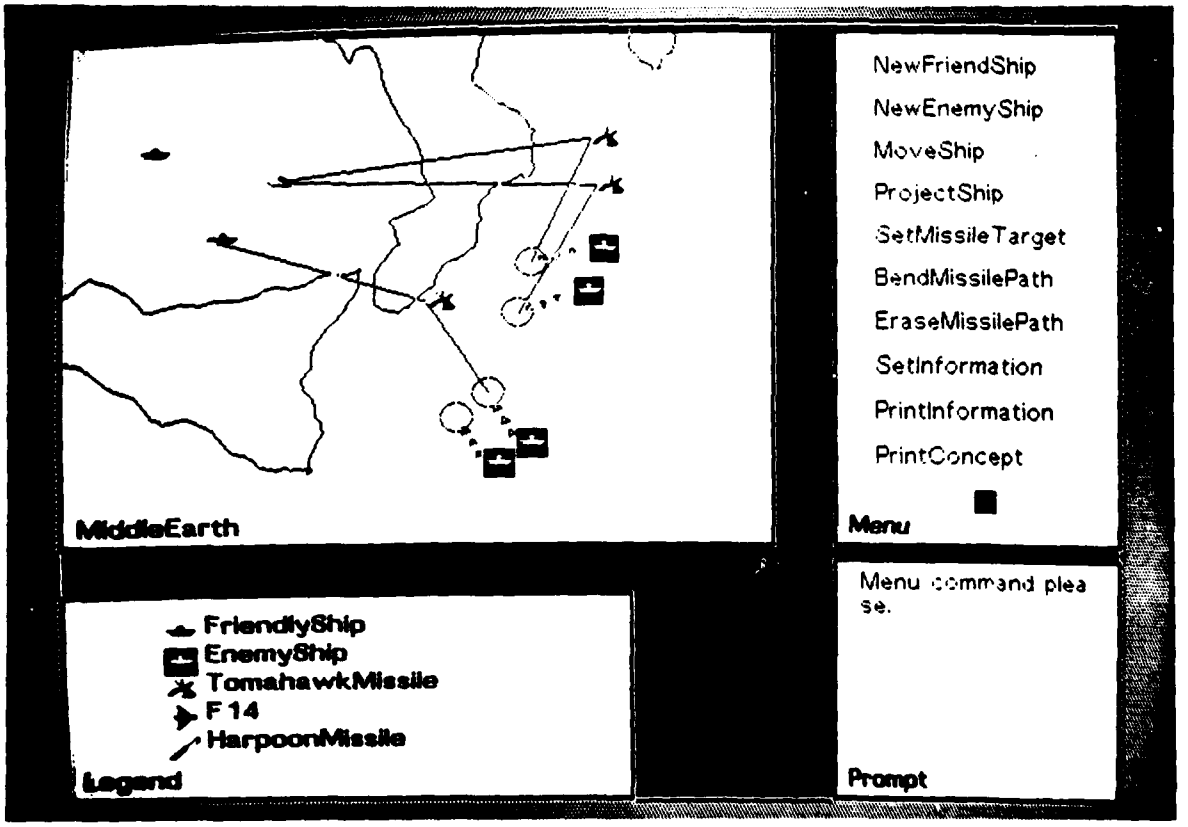


Figure 16.

The Middle Earth demonstration system is described in terms of six display regions. Four of these are on the screen view surface that represents the Conrac video monitor. The other two are on the screen view surface for the General Turtle display. Included on the Conrac are a map display region labelled Middle Earth, a Legend display region that contains a key to the map symbols, a Menu display used for controlling the demonstration program, and a Prompt display region in which the system prints prompting messages to the user. The General Turtle display contains a large general purpose text region and a much smaller system status region along the top edge of the screen. The former is used for printing some responses to the user's menu commands and for all interaction with the Interlisp interpreter. The latter contains a dynamically updated, one-line report on the presence of un-read electronic mail, system and group load average, and the currently connected directory.

Only three of the display regions are described as full graphics display regions. These are the Middle Earth, Legend and Menu regions on the Conrac. The other three are described as instances of TEXTDISPLAYREGION. Display forms are drawn on the graphics regions by adding the display form to be drawn to the graphics region's Occupant Role. Text is sent to the text display regions by ad hoc selection of the desired region with the function BMGTTYRegion and resort to the usual Interlisp print functions.

The Middle Earth map display region is initialized with some instances of DISPLAYFORM already in place. These are the individuals of POINTSLISTDISPLAYFORM that outline the island of Sicily and the "toe" and "heel" of the Italian boot. The Legend region is initialized with an instance of each of the map symbols coupled with a line of text indicating what the symbol is intended to represent. Each map symbol is an instance of TEXT in

which the Font Role specifies a special font set whose characters are small pictograms. The Menu display region contains nine lines of text, each of which can be selected by input from the graphic tablet. These represent various user commands to the demonstration program.

The first two options in the menu display region, which are tagged with the strings "NewFriendShip" and "NewEnemyShip", allow the user to insert symbols for friendly and enemy ships onto the map. The system first prints a prompting message requesting the user to input the desired location for the new track. When this has been done using the graphic tablet, a new instance of either FRIENDLYSHIPDF or OTHERSHIPDF (descendants of DISPLAYFORM) is added to the Occupant Role of the map display region, and thus drawn. The third menu item, denoted "MoveShip", allows the user to change a ship's location. With two successive prompts, the system asks the user to identify the ship to be moved and its new location, using the graphic tablet. The designated display form is then moved, and any other necessary changes to the map are made. For example, if the ship display form being moved is connected to one end or the other of a missile path display form, the path display form is adjusted to connect to the new location.

"ProjectShip", the fourth menu item, lets the user specify the projected location of a target ship at time of impact. The user is prompted to input the identity of the ship to be projected, and then the location that it is being projected to. The result on the display is a dashed circle at the projection location, connected to the ship symbol with a dashed arrow. Missile path forms, incidentally, are constrained to terminate at the destination end at some projection of a ship and never directly at a ship symbol. The fifth menu item, "SetMissileTarget", allows the user to specify a missile path between an attacker and a target. He or she is first prompted to

point at the attacking ship symbol, then the projected target symbol, and then a location for the elbow of a two-leg missile flight path. The missile path is drawn in the map display region as two straight lines connecting a ship symbol with a projection symbol, with a third symbol representing a Tomahawk missile at the join between them. The "BendMissilePath" menu option allows the user to change the location of the elbow of a missile path. First the path is pointed at and then the new location. The path is erased and then re-drawn to bend as specified. "EraseMissilePath" causes a designated path to be removed.

The "SetInformation" and "PrintInformation" items allow arbitrary strings input from the terminal to be attached to designated display forms. The last menu item, "PrintConcept", can be used to cause the KLONE concept associated with any visible display form to be printed in the general purpose text region on the General Turtle display.

8. CONCLUSION

This first year's effort has seen a number of important milestones in our exploration of a symbolic processing paradigm for command and control. Perhaps the most important of these is that a specific problem area has been selected to concentrate further incremental development of experimental systems: knowledge-based display management. This problem is central to the investigation of the paradigm, is of practical importance in the context of current C2 systems, and manifests a spectrum of issues in the construction of real-time, knowledge-based systems.

This project has helped to develop a powerful tool for building such systems: the KLONE knowledge representation language. In fact, AIPS is among the very first attempts of any extent to use KLONE, and this use has been instrumental in identifying problems with early versions of the language and driving its further refinement. An initial implementation of a prototype AIPS system was completed, and the results used to realize a pair of demonstration systems in widely differing domains. This initial set of descriptions and procedural attachments comprises a healthy nucleus for further growth.

At its inception, this effort was predicated on the availability of powerful and capacious symbolic processing hardware such as the MIT Interlisp machine. In fact, resources of this order did not become available. Nevertheless, an early demonstration program built around AIPS was made to run on a prototype LISP machine. That exercise at least established AIPS as a factual, real-time symbolic processing system. But the fact also remains that we still do not have this important hardware resource for system development purposes. Storage space limitations of the current Interlisp-10 system are becoming a critical problem.

As this report is written, AIPS has already been converted to run with a new and much expanded version of KLONE. We are rebuilding the bit-map display processor program so that it can better support the high-density, interactive, window-oriented display environments we envision. We are now entering a new cycle of design and implementation of AIPS proper. Among the issues we are concerned with are modifications that take advantage of the improvements to KLONE, reorganization and expansion of AIPS' presentation level into a repertoire of presentation formats, versatile description and implementation of display windows, and characterization of AIPS' dynamic behavior in response to changes in the domain model. We intend to complete this re-design by implementing a new and more ambitious demonstration application.

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APPENDIX A
AIPS KLONE NETWORK

Number of concepts: 73

[1]

```
Font
  type: Generic
  specializes: NUMBERP
  is role value of Font{Text}, Font{PersistentText}
  has attached data:
     Validity        NotTested
```

[2]

```
Presentation
  type: Generic
  has specializer: DerivedPresentation
  roles:
     DomainObject
       V/R = DomainObject
       Modality = Obligatory
     Style
       V/R = DisplayForm
       Modality = Obligatory
     Injection
       V/R = Injection
       Modality = Obligatory
       is modified by *Injection1*{DerivedPresentation}
  is role value of FromPresentation{DerivedPresentation}
  has attached procedures:
     (WHEN KLIndividuate NIL)
                    DeriveElaboration
  has attached data:
     Validity        NotTested
```

[3]

```
Injection
  type: Generic
  has specializer: DerivedInjection
  roles:
     CoordinateSystem
       V/R = CoordinateSystem
       is modified by *CoordinateSystem1*{DerivedInjection}
     DisplayRegion
       V/R = DisplayRegion
       Modality = Obligatory
     CoordinateSystemMapping
       V/R = CoordinateSystemMapping
       Modality = (Obligatory Derivable)
     ViewSurface
```

```
      V/R = ViewSurface
      is modified by *ViewSurface1*{DerivedInjection}
  is role value of FromInjection{DerivedInjection},
                   Injection{Presentation}
  has attached procedures:
     (WHEN KLIndividuate NIL)
                   AfterIndividuateInjection
  has attached data:
     Validity       NotTested
```

[4]

```
DomainObject
  type: Generic
  is role value of DomainObject{Presentation}
  has attached data:
     Validity       NotTested
```

[5]

```
DerivedPresentation
  type: Generic
  specializes: Presentation
  roles:
     *Injection1*
       Mods Injection{Presentation}
       V/R = DerivedInjection
     FromPresentation
       V/R = Presentation
  has attached data:
     Validity       NotTested
```

[6]

```
DerivedInjection
  type: Generic
  specializes: Injection
  roles:
     FromInjection
       V/R = Injection
     FromProjection
       V/R = Projection
     *CoordinateSystem1*
       Mods CoordinateSystem{Injection}
       Modality = (Obligatory Derivable)
     *ViewSurface1*
       Mods ViewSurface{Injection}
       Modality = (Obligatory Derivable)
  is role value of *Injection1*{DerivedPresentation}
```

```
  has attached procedures:
     (PRE KLDeriveRoles NIL)
                    DeriveDerivedInjectionRoles
  has attached data:
     Validity       NotTested
```

[7]

```
STRINGP
  type: Generic
  specializes: LISPDATA, PRINTP
  is role value of DisplayMode{DisplayRegion}
  has attached data:
     Validity       NotTested
```

[8]

```
RegularTriangle
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides1*
       Mods NumberOfSides{RegularPolygon}
       VAL = 3
  has attached data:
     Validity       NotTested
```

[9]

```
RegularSquare
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides2*
       Mods NumberOfSides{RegularPolygon}
       VAL = 4
  has attached data:
     Validity       NotTested
```

[10]

```
RegularPolygon
  type: Generic
  specializes: Polygon
  has specializers: RegularTriangle, RegularSquare,
                    RegularPentagon, RegularHexagon,
                    RegularHeptagon, RegularOctagon,
                    RegularNonagon, RegularDecagon,
                    RegularDodecagon
```

```
  roles:
     Center
       Diffs Argument{DisplayFormComposite}
       V/R = 2DimensionalPosition
     NumberOfSides
       Diffs Argument{DisplayFormComposite}
       V/R = NUMBERP
       is modified by *NumberOfSides1*{RegularTriangle},
                      *NumberOfSides2*{RegularSquare},
                      *NumberOfSides3*{RegularPentagon},
                      *NumberOfSides4*{RegularHexagon},
                      *NumberOfSides5*{RegularHeptagon},
                      *NumberOfSides6*{RegularOctagon},
                      *NumberOfSides7*{RegularNonagon},
                      *NumberOfSides8*{RegularDecagon},
                      *NumberOfSides9*{RegularDodecagon}
     LengthOfSide
       Diffs Argument{DisplayFormComposite}
       V/R = NUMBERP
  has attached IData:
     (HowToDraw NIL)
                    HTDRegularPolygon
     (HowToFindCenter NIL)
                    HTFCExplicitCenter
  has attached data:
     Validity       NotTested
```

[11]

```
RegularPentagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides3*
       Mods NumberOfSides{RegularPolygon}
       VAL = 5
  has attached data:
     Validity       NotTested
```

[12]

```
RegularOctagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides6*
       Mods NumberOfSides{RegularPolygon}
       VAL = 8
  has attached data:
```

```
    Validity        NotTested
```

[13]

```
RegularNonagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides7*
       Mods NumberOfSides{RegularPolygon}
       VAL = 9
  has attached data:
     Validity        NotTested
```

[14]

```
RegularHexagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides4*
       Mods NumberOfSides{RegularPolygon}
       VAL = 6
  has attached data:
     Validity        NotTested
```

[15]

```
RegularHeptagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides5*
       Mods NumberOfSides{RegularPolygon}
       VAL = 7
  has attached data:
     Validity        NotTested
```

[16]

```
RegularDodecagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides9*
       Mods NumberOfSides{RegularPolygon}
       VAL = 12
  has attached data:
     Validity        NotTested
```

[17]

```
RegularDecagon
  type: Generic
  specializes: RegularPolygon
  roles:
     *NumberOfSides8*
       Mods NumberOfSides{RegularPolygon}
       VAL = 10
  has attached data:
     Validity        NotTested
```

[18]

```
Pentagon
  type: Generic
  specializes: Polygon
  roles:
     *Side1*
       Mods Side{Polygon}
       Number = 5
  has attached data:
     Validity        NotTested
```

[19]

```
Octagon
  type: Generic
  specializes: Polygon
  roles:
     *Side2*
       Mods Side{Polygon}
       Number = 8
  has attached data:
     Validity        NotTested
```

[20]

```
Nonagon
  type: Generic
  specializes: Polygon
  roles:
     *Side3*
       Mods Side{Polygon}
       Number = 9
  has attached data:
     Validity        NotTested
```

[21]

```
Hexagon
  type: Generic
  specializes: Polygon
  roles:
     *Side4*
       Mods Side{Polygon}
       Number = 6
  has attached data:
     Validity        NotTested
```

[22]

```
Heptagon
  type: Generic
  specializes: Polygon
  roles:
     *Side5*
       Mods Side{Polygon}
       Number = 7
  has attached data:
     Validity        NotTested
```

[23]

```
Dodecagon
  type: Generic
  specializes: Polygon
  roles:
     *Side6*
       Mods Side{Polygon}
       Number = 12
  has attached data:
     Validity        NotTested
```

[24]

```
Decagon
  type: Generic
  specializes: Polygon
  roles:
     *Side7*
       Mods Side{Polygon}
       Number = 10
  has attached data:
     Validity        NotTested
```

[25]

```
Triangle
  type: Generic
  specializes: Polygon
  roles:
     *Side8*
       Mods Side{Polygon}
       Number = 3
  has attached data:
     Validity        NotTested
```

[26]

```
Trapezoid
  type: Generic
  specializes: Quadrilateral
  has attached data:
     Validity        NotTested
```

[27]

```
Text
  type: Generic
  specializes: DisplayFormPrimitive
  roles:
     String
       V/R = PRINTP
     Position
       V/R = Position
     Font
       V/R = Font
  is role value of Label{DisplayRegion}
  has attached IData:
     (HowToDraw NIL)
                     HTDText
     (HowToErase NIL)
                     HTEText
     (HowToFindCenter NIL)
                     HTFCExplicitPosition
  has attached data:
     Validity        NotTested
```

[28]

```
Square
  type: Generic
  specializes: Rectangle, Rhombus
  has attached data:
     Validity        NotTested
```

[29]

```
Rhombus
  type: Generic
  specializes: Parallelogram
  has specializer: Square
  has attached data:
     Validity        NotTested
```

[30]

```
Rectangle
  type: Generic
  specializes: Parallelogram
  has specializer: Square
  has attached data:
     Validity        NotTested
```

[31]

```
Quadrilateral
  type: Generic
  specializes: Polygon
  has specializers: Parallelogram, Trapezoid
  roles:
     *Side9*
       Mods Side{Polygon}
       Number = 4
  has attached data:
     Validity        NotTested
```

[32]

```
Polygon
  type: Generic
  specializes: DisplayFormComposite
  has specializers: Triangle, Quadrilateral, Pentagon,
                    Hexagon, Heptagon, Octagon, Nonagon,
                    Decagon, Dodecagon, RegularPolygon
  roles:
     Side
       Diffs Piece{DisplayFormComposite}
       V/R = Line
       Number = (3 NIL)
       is modified by *Side8*{Triangle},
                      *Side9*{Quadrilateral},
                      *Side1*{Pentagon}, *Side4*{Hexagon},
                      *Side5*{Heptagon}, *Side2*{Octagon},
```

```
                        *Side3*{Nonagon}, *Side7*{Decagon},
                        *Side6*{Dodecagon}
  has attached data:
     Validity        NotTested
```

[33]

```
DEFAULT
  type: Generic
  has attached data:
     Validity        NotTested
```

[34]

```
Point
  type: Generic
  specializes: DisplayFormPrimitive
  roles:
     Position
       V/R = 2DimensionalPosition
  has attached IData:
     (HowToDraw NIL)
                     HTDPoint
     (HowToErase NIL)
                     HTEPoint
     (HowToFindCenter NIL)
                     HTFCExplicitPosition
  has attached data:
     Validity        NotTested
```

[35]

```
PersistentText
  type: Generic
  specializes: DisplayFormPrimitive
  roles:
     String
       V/R = PRINTP
     Position
       V/R = Position
     Font
       V/R = Font
  has attached IData:
     (HowToDraw NIL)
                     HTDText
     (HowToErase NIL)
                     HTEText
     (HowToFindCenter NIL)
                     HTFCExplicitPosition
```

```
  has attached data:
     Validity        NotTested
```

[36]

```
PersistentCircle
  type: Generic
  specializes: DisplayFormPrimitive
  roles:
     Center
       V/R = Position
     Radius
       V/R = CoordinateDistance
  has attached IData:
     (HowToErase NIL)
                     HTECircle
     (HowToFindCenter NIL)
                     HTFCExplicitCenter
  has attached data:
     Validity        NotTested
```

[37]

```
Parallelogram
  type: Generic
  specializes: Quadrilateral
  has specializers: Rectangle, Rhombus
  has attached data:
     Validity        NotTested
```

[38]

```
Line
   type: Generic
   specializes: DisplayFormPrimitive
   has specializer: ConnectingLine
   roles:
      EndPosition
        V/R = 2DimensionalPosition
        Number = 2
        is modified by *EndPosition1*{ConnectingLine}
   is role value of Side{Polygon}
   has attached IData:
      (HowToDraw NIL)
                     HTDLine
      (HowToErase NIL)
                     HTELine
      (HowToFindCenter NIL)
                     HTFCMidLinePosition
```

```
  has attached data:
     Validity        NotTested
```

[39]

```
DisplayFormPrimitive
  type: Generic
  specializes: DisplayForm
  has specializers: Line, Point, Circle, PersistentCircle,
                    Text, PersistentText
  has attached data:
     Validity        NotTested
```

[40]

```
LITATOM
  type: Generic
  specializes: ATOM, PRINTP
  has attached data:
     Validity        NotTested
```

[41]

```
LISTP
  type: Generic
  specializes: LISPDATA
  has attached data:
     Validity        NotTested
```

[42]

```
DisplayFormComposite
  type: Generic
  specializes: DisplayForm
  has specializer: Polygon
  roles:
     Argument
       is differentiated by Center{RegularPolygon},
                            NumberOfSides{RegularPolygon},
                            LengthOfSide{RegularPolygon}
     Piece
       V/R = DisplayForm
       is differentiated by Side{Polygon}
  has attached IData:
     (HowToDraw NIL)
                    HTDComposite
     (HowToErase NIL)
                    HTEComposite
     (HowToFindCenter NIL)
```

```
                    HTFCCenterOfPieces
      (HTCDistanceSquaredFromDF NIL)
                    HTCDistanceDFComposite
  has attached data:
     Validity       NotTested
```

[43]

```
DisplayForm
  type: Generic
  has specializers: DisplayFormPrimitive,
                    DisplayFormComposite
  is role value of Piece{DisplayFormComposite},
                   DisplayForm{ConnectingLine},
                   Style{Presentation},
                   Occupant{DisplayRegion}
  has attached data:
     Validity       NotTested
```

[44]

```
ConnectingLine
  type: Generic
  specializes: Line
  roles:
     DisplayForm
       V/R = DisplayForm
       Number = 2
     *EndPosition1*
       Mods EndPosition{Line}
       Modality = (Obligatory Derivable)
  has attached procedures:
     (PRE KLDeriveRoles NIL)
                    DeriveConnectingLinePositions
  has attached data:
     Validity       NotTested
```

[45]

```
SMALLP
  type: Generic
  specializes: NUMBERP
  has attached data:
     Validity       NotTested
```

[46]

```
Circle
  type: Generic
```

```
  specializes: DisplayFormPrimitive
  roles:
     Center
       V/R = 2DimensionalPosition
     Radius
       V/R = Magnitude
  has attached IData:
     (HowToDraw NIL)
                    HTDCircle
     (HowToErase NIL)
                    HTECircle
     (HowToFindCenter NIL)
                    HTFCExplicitCenter
  has attached data:
     Validity       NotTested
```

[47]

```
WhiteOnBlack
  type: Generic
  specializes: VideoSense
  has attached data:
     Validity       NotTested
```

[48]

```
ViewSurface
  type: Generic
  has specializer: ScreenViewSurface
  roles:
     CoordinateSystem
       V/R = CartesianCoordinateSystem
  is role value of FromSurface{Projection},
                   ToSurface{Projection},
                   ViewSurface{Injection}
  has attached data:
     Validity       NotTested
```

[49]

```
VideoSense
  type: Generic
  has specializers: BlackOnWhite, WhiteOnBlack
  is role value of VideoSense{ScreenViewSurface}
  has attached data:
     Validity       NotTested
```

[50]

```
ScreenViewSurface
  type: Generic
  specializes: ViewSurface
  roles:
     VideoPlane
       V/R = NUMBERP
     VideoSense
       V/R = VideoSense
     FullScreenDisplayRegion
       V/R = DisplayRegion
  is role value of Screen{DisplayRegion}
  has attached procedures:
     (WHEN KLIndividuate NIL)
                    SetScreenVideoSense
  has attached data:
     Validity       NotTested
```

[51]

```
Projection
  type: Generic
  roles:
     FromSurface
       V/R = ViewSurface
     ToSurface
       V/R = ViewSurface
     CoordinateSystemMapping
       V/R = CoordinateSystemMapping
  is role value of FromProjection{DerivedInjection}
  has attached procedures:
     (WHEN KLIndividuate NIL)
                    DeriveInjectionAfterIndividuateProjection
  has attached data:
     Validity       NotTested
```

[52]

```
HitPosition
  type: Generic
  specializes: CartesianPosition
  has attached data:
     Validity       NotTested
```

[53]

```
Position
  type: Generic
  has specializer: 2DimensionalPosition
  roles:
```

```
    Coordinate
      V/R = NUMBERP
      is differentiated by X{2DimensionalPosition},
                           Y{2DimensionalPosition}
  is role value of Position{CoordinateSystem},
                   1,1{CoordinateTransformationFn},
                   0,0{CoordinateTransformationFn},
                   UpperRight{CoordinateSystemWindow},
                   LowerLeft{CoordinateSystemWindow},
                   Center{PersistentCircle}, Position{Text},
                   Position{PersistentText}
  has attached data:
     Validity       NotTested
```

[54]

```
TextDisplayRegion
  type: Generic
  specializes: DisplayRegion
  roles:
     InnerRegionNumber
       V/R = NUMBERP
       Modality = (Obligatory Derivable)
  has attached procedures:
     (WHEN KLIndividuate TextDRLockOut)
                   AfterIndividuateTextDisplayRegion
  has attached data:
     Validity       NotTested
```

[55]

```
DisplayRegion
  type: Generic
  has specializer: TextDisplayRegion
  roles:
     Screen
       V/R = ScreenViewSurface
     Window
       V/R = CoordinateSystemWindow
     Background
       V/R = NUMBERP
     RegionNumber
       V/R = NUMBERP
     DisplayMode
       V/R = STRINGP
     Label
       V/R = Text
       has attached procedures:
          (WHEN KLSatisfyRole NIL)
```

```
                          AfterSatisfyLabelRole
          (WHEN KLChangeRoleValue NIL)
                          AfterChangeLabelRole
     Occupant
       V/R = DisplayForm
       Number = (0 NIL)
       has attached procedures:
          (WHEN KLSatisfyRole NIL)
                          AfterSatisfyOccupantRole
  is role value of

FullScreenDisplayRegion{ScreenViewSurface},
                    DisplayRegion{Injection}
  has attached procedures:
     (WHEN KLIndividuate TextDRLockOut)
                     AfterIndividuateDisplayRegion
  has attached data:
     Validity       NotTested
```

[56]

```
CoordinateTransformationFn
  type: Generic
  roles:
     1,1
       V/R = Position
     0,0
       V/R = Position
  is role value of

CoordinateTransformationFn{CoordinateSystemMapping}
  has attached data:
     Validity       NotTested
```

[57]

```
CoordinateSystemWindow
  type: Generic
  roles:
     UpperRight
       V/R = Position
     LowerLeft
       V/R = Position
  is role value of Window{DisplayRegion},
                   FromWindow{CoordinateSystemMapping},
                   ToWindow{CoordinateSystemMapping}
  has attached data:
     Validity       NotTested
```

[58]

```
CoordinateSystemMapping
  type: Generic
  roles:
     FromWindow
       V/R = CoordinateSystemWindow
     ToWindow
       V/R = CoordinateSystemWindow
     CoordinateTransformationFn
       V/R = CoordinateTransformationFn
     InverseMapping
       V/R = CoordinateSystemMapping
       Modality = (Obligatory Derivable)
  is role value of CoordinateSystemMapping{Projection},
                   InverseMapping{CoordinateSystemMapping},
                   CoordinateSystemMapping{Injection}
  has attached procedures:
     (WHEN KLIndividuate NIL)
                    AfterIndividuateCoordinateSystemMapping
  has attached data:
     Validity       NotTested
```

[59]

```
CoordinateSystem
  type: Generic
  has specializer: 2DimensionalCoordinateSystem
  roles:
     Position
       V/R = Position
  is role value of CoordinateSystem{CoordinateDistance},
                   CoordinateSystem{Injection}
  has attached data:
     Validity       NotTested
```

[60]

```
CoordinateDistance
  type: Generic
  roles:
     CoordinateSystem
       V/R = CoordinateSystem
     Magnitude
       V/R = NUMBERP
  is role value of Radius{PersistentCircle}
  has attached data:
     Validity       NotTested
```

[61]

```
CartesianPosition
  type: Generic
  specializes: 2DimensionalPosition
  has specializer: HitPosition
  roles:
     Abcissa
       Diffs X{2DimensionalPosition}
     Ordinate
       Diffs Y{2DimensionalPosition}
  has attached data:
     Validity        NotTested
```

[62]

```
CartesianCoordinateSystem
  type: Generic
  specializes: 2DimensionalCoordinateSystem
  is role value of CoordinateSystem{ViewSurface}
  has attached data:
     Validity        NotTested
```

[63]

```
BlackOnWhite
  type: Generic
  specializes: VideoSense
  has attached data:
     Validity        NotTested
```

[64]

```
2DimensionalPosition
  type: Generic
  specializes: Position
  has specializer: CartesianPosition
  roles:
     X
       Diffs Coordinate{Position}
       is differentiated by Abcissa{CartesianPosition}
     Y
       Diffs Coordinate{Position}
       is differentiated by Ordinate{CartesianPosition}
  is role value of EndPosition{Line}, Position{Point},
                   Center{Circle}, Center{RegularPolygon}
  has attached data:
     Validity        NotTested
```

[65]

```
2DimensionalCoordinateSystem
  type: Generic
  specializes: CoordinateSystem
  has specializer: CartesianCoordinateSystem
  has attached data:
     Validity       NotTested
```

[66]

```
NUMBERP
  type: Generic
  specializes: ATOM
  has specializers: FIXP, FLOATP, SMALLP, Magnitude, Font
  is role value of Magnitude{CoordinateDistance},
                   Coordinate{Position},
                   VideoPlane{ScreenViewSurface},
                   Background{DisplayRegion},
                   RegionNumber{DisplayRegion},
                   InnerRegionNumber{TextDisplayRegion},
                   NumberOfSides{RegularPolygon},
                   LengthOfSide{RegularPolygon}
  has attached data:
     Validity       NotTested
```

[67]

```
PRINTP
  type: Generic
  has specializers: LITATOM, STRINGP
  is role value of String{Text}, String{PersistentText}
  has attached data:
     Validity       NotTested
```

[68]

```
Magnitude
  type: Generic
  specializes: NUMBERP
  is role value of Radius{Circle}
  has attached data:
     Validity       NotTested
```

[69]

```
FLOATP
  type: Generic
  specializes: NUMBERP
```

```
  has attached data:
     Validity       NotTested
```

[70]

```
DEFAULTVALUE
  type: Generic
  has attached data:
     Validity       NotTested
```

[71]

```
LISPDATA
  type: Generic
  has specializers: ATOM, LISTP, STRINGP
  has attached data:
     Validity       NotTested
```

[72]

```
FIXP
  type: Generic
  specializes: NUMBERP
  has attached data:
     Validity       NotTested
```

[73]

```
ATOM
  type: Generic
  specializes: LISPDATA
  has specializers: NUMBERP, LITATOM
  has attached data:
     Validity       NotTested
```

APPENDIX B
BIT MAP GRAPHICS FUNCTIONS

BMGGraphicsRegion(Region)

- Sets the graphics region to be Region.

BMGTTYRegion(Region)

- Sets the TTY region for all following operations. If Region is negative, the local, printing terminal is used instead of a bitmap region.

BMGResetTTY()

- The TTY region is cleaned, filled with its background shade, and the current point set at the left boundary ready to start the first line of text.

BMGVideoDefault(Mode)

- Sets the sense of the video signal. Mode refers to the backgraound: BLACK or WHITE.

BMGVideoSense(Plane,Mode)

- Sets the sense of the video on plane Plane to Mode. Mode is either BLACKONWHITE or WHITEONBLACK.

BMGLimits(MaxX,MinX,MaxY,MinY)

- Sets the boundaries of the graphics region.

BMGPlane(Plane)

- Sets the plane of the graphics region to be Plane. Currently 0 is the General Turtle monitor (12", P39 phosphor), and 1 is the CONRAC monitor (17", P4 phosphor).

BMGRelativeCoordinates(Flag)

- If Flag is non-NIL, then graphics operations in the current graphics region will be understood in relative coordinates. If Flag is NIL, then screen coordinates will be used.

BMGBias(X,Y)

- Sets the bias (origin) of the current graphics region to (X Y).

BMGDisplayMode(Mode)

- Sets the display mode of the graphics region. Mode is one of ADD, REMOVE, FLIP, OVERWRITE.

BMGFont(Font)

- Sets the font of the graphics region. Font is a small integer.

BMGTTYFont(Font)

- Sends font change escapse sequence down the TTY stream.

BMGScroll(Distance)

- Sets the scrolling characteristics of the graphics region. Distance is the number of lines to scroll up at a hop; if Distance is zero, the whole region is cleaned instead of scrolling.

BMGBackground(Grey)

- Sets the background shade of the graphics region. Grey is a 16-bit integer describing a 4 by 4 pattern of bits: the bits of the top line of this pattern are the low-order 4 bits of Grey, the second line provides the next 4 bits, and so on; thus 0 means no bits, -1 means all bits, 122643Q is every other point, and 116143Q is top-right to bottom-left slashes.

BMGFill(Grey)

- The graphics region is filled with the pattern of shading indicated by Grey (see BMGBackGround). The filling is affected by display mode (OVERWRITE is not the same as ADD).

BMGRelocateRegion(X,Y)

- Translates the graphics region so that its top left corner is at (X,Y). This moves all the bits in the region and changes its limits.

BMGMoveRegion(FromRegion,ToRegion)

- The ToRegion is filled with the contents of the FromRegion. The top left bits of FromRegion are drawn into the top left bits of the ToRegion. The boundaries of the ToRegion determine how much is moved; the boundaries of the FromRegion are ignored. The filling is affected by the display mode of the ToRegion.

BMGMove(X,Y)

- Makes (X,Y) the current point of the graphics region.

BMGMoveRelative(DeltaX,DeltaY)

- Like BMGMove, except that the point moved to is the vector sum of (DeltaX,DeltaY) and the current point.

BMGPoint(X,Y)

- Draws a point at (X,Y). If outside the graphics region it does not appear. Note that "drawing" is done in the display mode of the graphics region (in this case, OVERWRITE has the same effect as ADD).

BMGPointRelative(DeltaX,DeltaY)

- Like BMGPoint, except that the point at which the point is drawn is the vector sum of (DeltaX,DeltaY) and the current point.

BMGLine(X,Y)

- Draws a line from the current point of the graphics region to (X,Y). Sets the current point to be (X,Y). If outside the graphics region, it is clipped. Drawing is affected by display mode (see BMGPoint).

BMGLineRelative(DeltaX,DeltaY)

- Like BMGLine, except that the line is drawn (from the current point) to the vector sum of (DeltaX,DeltaY) and the current point.

BMGCircle(X,Y,R)

- Draws a circle with no change to the current point.

BMGEllipse(X,Y,A,B)

- Draws a horizontal or vertical ellipse by a set of straight lines, the number dependent on the size of the ellipse.

BMGString(Text)

- PRIN3 is applied to Text. The result is drawn at the current point of the graphics region. Characters outside the graphics region do not appear. The current point of the graphics region is left at the end of the text: that is, use of this function without intervening movement of the current point of the graphics region will append characters to the drawn characters in a reasonable way. Formatting characters do not have a formatting effect; they are drawn as a pattern of bits just as every other character is. Drawing is affected by display mode (OVEWRITE is not the same as ADD).

BMGGetCurrentPosition()

- Gets the current xy position in the current graphics region.

BMGGetStringSize(String)

- Returns a pair with the maximum length of the string in bit positions as if printed in the current graphics region with its current font. The y coordinate is the font height times the number of line feeds in the string.

BMGTTYCursor(Flag)

- Activates (or deactivates) the TTY cursor.

BMGTablet(How)

- Activates or deactives the tablet.

BMGTabletPlane(Plane)

- Sets the plane for the tablet cursor.

BMGTabletCursorShape(UpShape,DownShape)

- Changes the cursor shape. UpShape and DownShape are arrays of (at least) 20 words: 16 for the raster, and one each for offsetx, offsety, height, and width.

BMGGetHit()

- Waits for and returns a hit pair: CAR is X, CDR is Y.

BMGPrintOperations(Flag)

- *For debugging*: if Flag is non-NIL, then the BMG operations cause printout on the terminal (if you're using the BMG at the time, this will be in the TTY region). If Flag is NIL, BMG operations will begin to have their BMG effect.